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Research and Development Report

MOBILE BROADBAND SYSTEM

A Report on the work of RACE Project 2067

J.T. Zubrzycki, B.Sc.(Eng.), Ph.D., C.Eng., M.I.E.E.

Research and Development
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THE BRITISH BROADCASTING CORPORATION

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Summary

Mobile Broadband System (MBS) is a wireless cellular radio network capable of carrying digital signals at bit rates sufficient for digital video, including compressed HDTV. The technological feasibility has been studied in RACE Project 2067 MBS, which had the aim to extend the Broadband Integrated Services Digital Network (B-ISDN) to mobile users, providing much higher capacity to users than current digital mobile cellular systems. MBS potentially offers broadcasters a public system to obtain dial-up high bit-rate connections for electronic news gathering. Also, broadcasters could set up their own cellular systems at outside broadcasts and in studios in order to make greater use of radio-cameras and radio-microphones. The benefit of using MBS-compatible hardware is the economics of scale expected from its introduction as a public network. The results of trials of an MBS technology demonstrator are reported, which confirm the feasibility of millimetric-waveband transmission of digital video at 60 GHz. The success of the RACE MBS project has given rise to a new ACTS** project called SAMBA (System for Advanced Mobile Broadband Applications) to continue the development of the MBS concept into an operational system.*

* Research and development in Advanced Communications technologies for Europe.

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1. INTRODUCTION

New second generation mobile radio communications systems based on digital technology, such as GSM (Global System for Mobile communications), are presently coming into operation. They have a limited capacity, so are mainly suited to highly compressed voice coding (e.g. 3.4 kHz audio bandwidth signals coded at 13 kbits/s). Though some systems can also carry data at about 9.6 kbits/s, the mobile industry is aware of the increasing demand for more capacity; therefore, the development of third generation mobile systems is already well advanced. The main effort is being directed towards the Universal Mobile Telecommunications System (UMTS)* which is primarily aimed at providing voice and data at the ISDN basic rate (144 kbits/s), with the upper limit being in the region of 2 Mbits/s. There is still much debate as to whether any higher capacity is required by the majority of users, but there is little doubt that even these rates are still too low for many requirements in the broadcast industry.

The concept behind the Mobile Broadband System (MBS), developed in RACE Project 2067 MBS, was to provide Broadband Integrated Services Digital Network (B-ISDN) services to mobile users through dial-up Asynchronous Transfer Mode (ATM) connections at up to 34 Mbits/s[1,2]. This is a simple statement that indicates an important difference in the way MBS operates in comparison with other systems. MBS does not intend to be directly concerned with the type of information being carried. Voice or video will not be transcoded at the boundary between MBS and the fixed B-ISDN. It will be up to the user's terminal to configure itself to take into account the capacity and quality of the link that has been established. This concept provides the maximum flexibility to meet a wide range of applications.

The RACE MBS project has now completed a four-year work programme with a demonstration of the technological feasibility of broadband communication with mobiles. This Report gives an outline of MBS, its possible applications to broadcasters and the results of trials with the technology demonstrator (carrying both digital video and audio signals).

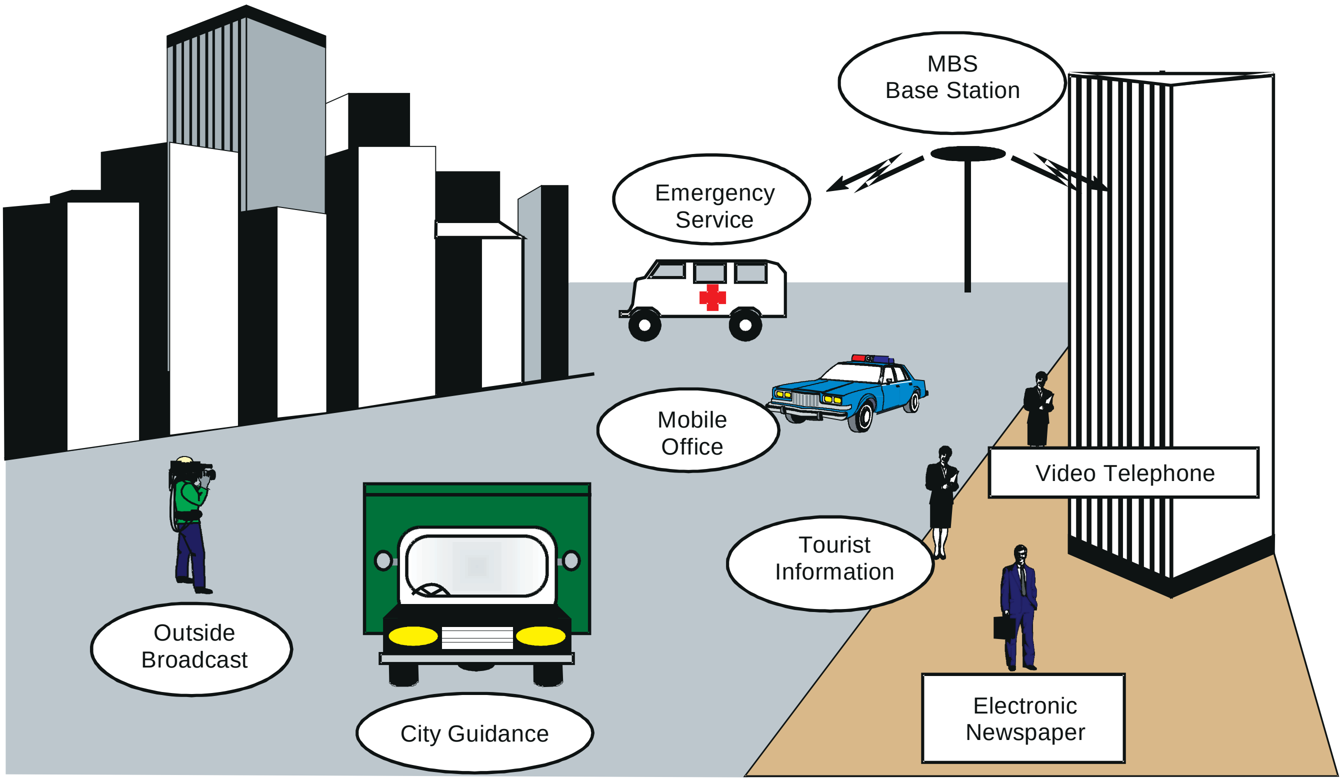

Fig. 1 - A public MBS cell.

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* Also known as FLMPTS — Future Public Land Mobile Telecommunications Service.

2. DESCRIPTION OF MBS

2.1 Overview

MBS is primarily intended to be a public cellular radio system, communicating with the mobile users via base stations installed along roads (Fig. 1 *(previous page)*), railways and public areas; so creating a network of radio cells[3] providing multi-megabit bidirectional communications with the mobile users. Studies within the RACE project have shown that there is also a potential market for systems to be installed in Customer Premises Networks (CPN) to provide a high capacity wireless Local Area Network (LAN) cum private exchange. In this case, each room would be a separate radio cell. Fig. 2 shows that not only would MBS offer B-ISDN services to mobile users, but that it would encompass the lower bit-rate services offered by UMTS and GSM. This does not mean that an MBS terminal will be able to access GSM at the radio interface; instead, it will interwork with other systems at the ATM level via the fixed network, as shown in Fig. 3. By fully supporting ATM, standard user terminal equipment with ATM interfaces can be used. To ensure a high-reliability operation, the ATM packets would be error-protected for transmission over the radio path.

The capacity of the radio channel depends on the frequency bands available, the number of other users in each radio cell and the hardware constraints. To provide a service for several high capacity users simultaneously, a bandwidth of the order of 1 GHz is required; consequently forcing the use of available frequencies in the millimetric wavebands. Atmospheric attenuation rises with frequency and there are absorption bands due to water vapour and oxygen, as shown in Fig. 4. The MBS project has proposed the use of two wavebands: the 60 GHz band for very small cells (picocells), and the 40 GHz for larger cells. The project's proposals have been incorporated into the Detailed Spectrum Investigation carried out by the European Radiocommunications Office[4], and are summarised in Fig. 5. Two 1 GHz allocations are proposed in each band; one for the uplink (mobile-to-base) and the other for the downlink. There is a sufficient frequency difference between the up- and downlinks to simplify filtering in the mobile, thereby allowing a single antenna to be used with a diplexer.

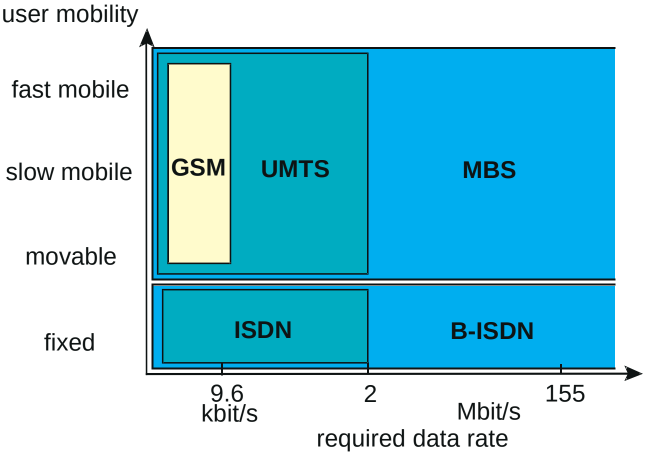


Fig. 2 - Relationship of MBS to other systems.

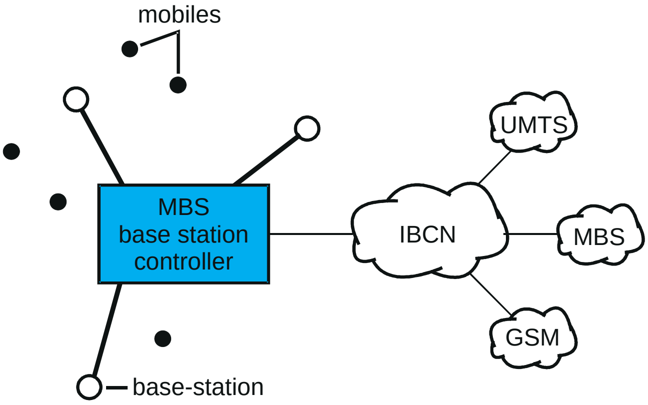


Fig. 3 - Interworking of MBS with other mobile networks.

At first sight, the 40 GHz band would be thought to be the first choice, but this is not so. To maximise the number of high-capacity users in an area, the cell size must be small and the attenuation between cells be high, to increase frequency re-use. The small cell size also enables the coverage to be tailored to match the local geography and helps to target services to specific areas.

2.2 System parameters

Though the RACE project has finished, MBS is still subject to further development and standardisation, so the system parameters are likely to evolve. The following description therefore represents the situation at the time of writing.

The service bit-rate per radio frequency (RF) carrier is expected to be up to 34 Mbits/s[5]. This is a value that accounts for the significant multipath propagation that will generally occur when MBS is used in real situations. City street conditions would be typical, where time-varying fading and differential Doppler frequency shifts make reception more difficult, particularly as the mobile speed increases. MBS is intended to initially work with mobile speeds up to 50 km/h in urban areas; then at motorway speeds (over 100 km/h), with special enhancements for high speed trains (300 km/h) and other applications.

Higher service bit-rates would be provided by using several RF carriers in parallel, which is expected to be cost effective (due to the large-scale integration of the RF circuitry as MBS hardware goes into volume production).

Modulation methods studied within the RACE project included 4-Offset Quadrature Amplitude Modulation (OQAM) and Frequency Shift Keying (FSK), which have a near-constant envelope; also, 16-OQAM for higher capacity and OFDM (Orthogonal Frequency Division Multiplexing) for more rugged reception, but which have the disadvantage of needing linear power amplifiers.

User access is expected to be by Time Division Multiple Access (TDMA), at least initially, although Code Division Multiple Access (CDMA) techniques were also considered. These techniques split the transmitted data into a series of packets, enabling several mobiles to communicate within a cell simultaneously. An adaptive equaliser can be used in the receiver to combat the distortion to the frequency response of the channel caused by multipath propagation. The class of equalisers being considered for MBS require a known training sequence of bits to be inserted into the transmitted packet. The equaliser can then use these bits to set the values of its tap coefficients. Since the channel characteristics can change very quickly at high mobile speeds, the training sequence is often put in the middle of the packet to minimise any errors for data towards the ends.

The signal will contain error protection, using Forward Error Correction (FEC) by combined convolutional and Reed-Solomon coding, typically doubling the transmitted bit-rate. In addition, for situations where the depth of fade is too long for the FEC, the repeated transmission of corrupted packets using Automatic Repeat reQuest (ARQ) is available. If the second packet is also corrupted, the technique of changing the FEC used on the repeated packet would enable a comparison of the two packets to recover the data, thus reducing the probability of having to send the packet a third time[6].

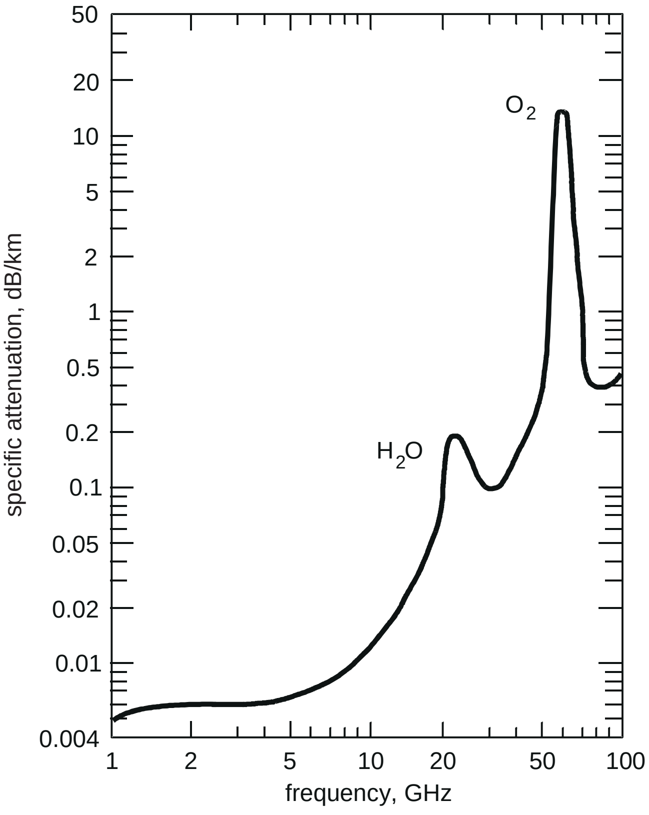
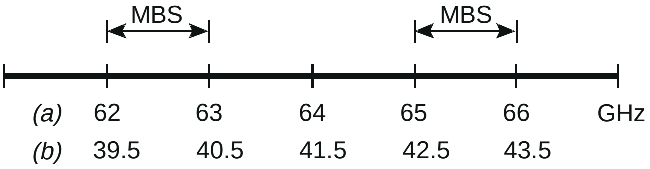


Fig. 4 - Atmospheric attenuation against frequency.



(a) - 60 GHz band proposal
(b) - 40 GHz band proposal

Fig. 5 - Proposed MBS frequency allocations.

Propagation at 60 GHz is similar to optical propagation, due to the short wavelength. Like a light beam reflecting off a mirror, obstacles produce specular reflections in front and shadowing behind, with only small amounts of diffraction. In urban or indoor environments there are many vertical and horizontal surfaces to contribute reflections, resulting in multipath propagation. Studies of materials in the project have shown that most surfaces produce large reflections, unless the size of the surface features is comparable with the RF wavelength (e.g. patterned glass), then the reflections are more diffuse. The project has developed a software simulator to model the RF system, and two channel sounders have been constructed to obtain indoor and outdoor propagation data[7,8].

The propagation studies using the current antenna and RF front-end parameters suggest that the transmission range achievable for the first systems will be about 100 m at 60 GHz, which is ideal for use in city centres or indoors. It is expected that this range will increase as the 60 GHz electronics and antennas develop, although greater range would be possible by using 40 GHz, due to a combination of lower atmospheric attenuation and better electronics.

The base station antenna needs to have a radiation pattern that minimises variation of field strength within the cell, has a sharp roll-off at the edge of the cell and does not have any nulls in the pattern for mobiles passing under the antenna. This has been achieved in the project by using a specially shaped dielectric lens antenna as shown in Fig. 6 *(overleaf)* and its radiation pattern in Fig. 7 *(overleaf)*[9]. The prototypes have been machined out of Plexiglas, but mass production could use injection moulding techniques.

The effect of high levels of multipath cannot be alleviated solely by using FEC and ARQ error protection, because there is the possibility for a mobile to stop in such a position that its antenna is in the middle of a fade, so antenna diversity is used. Experience from radio systems operating at lower frequencies shows that antenna separation needs to be several wavelengths (only a few centimetres in the 60 GHz band) to produce decorrelated fading at each antenna.

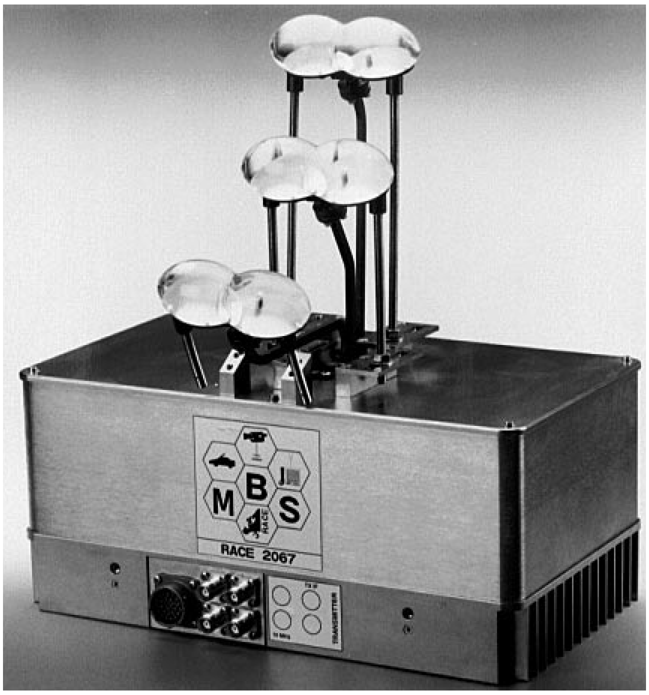


Fig. 6 - Dielectric lens antenna assembly.

The MBS project has carried out detailed studies and simulations of operational system aspects of a fully functioning MBS. These include call set-up procedures, mobility management, allocation of available capacity, protocols for interworking with the fixed network, etc.; aspects that are too complex to describe here, but details are given in the References 10, 11 and 12.

Handover of the communication channel from one cell to the next, as the mobile crosses cell boundaries, has been an important area of study in the project to keep the signalling overhead to a minimum without losing user information. Soft handover is the most reliable because the mobile is in simultaneous contact with two base stations during the handover period, but it can be wasteful of system resources, due to duplicating the data transfer via two cells. Hard handover has the risk that transfer of communication to the new cell may not occur immediately, due to shadowing or multipath leaving a gap and potential loss of user data, or even dropping the connection. Verification of the various handover techniques studied in the project could not be carried out because the project's demonstrator has only one cell. However, a new follow-on project will be able to test the results of these studies (see Section 5).

2.3 Microwave integrated circuits

Much of the success of MBS hinges on the ability to mass produce low-cost Monolithic Microwave Integrated Circuits (MMICs) for 40 or 60 GHz operations[13]. The 60 GHz MMICs for the RACE project have been made in collaboration with another European project called 'CLASSIC'. They employ gallium arsenide pseudomorphic high-electron-mobility transistors (PHEMTs) with a gate length of about 0.2 µm. Fabrication processes used in the project are rapidly gaining maturity, and they are providing design data which is being incorporated into electrical models. As these models become more accurate, they enable the subsequent generations of MMICs to be manufactured more efficiently. It is estimated that the cost of the MMICs will not be a limiting factor in MBS.

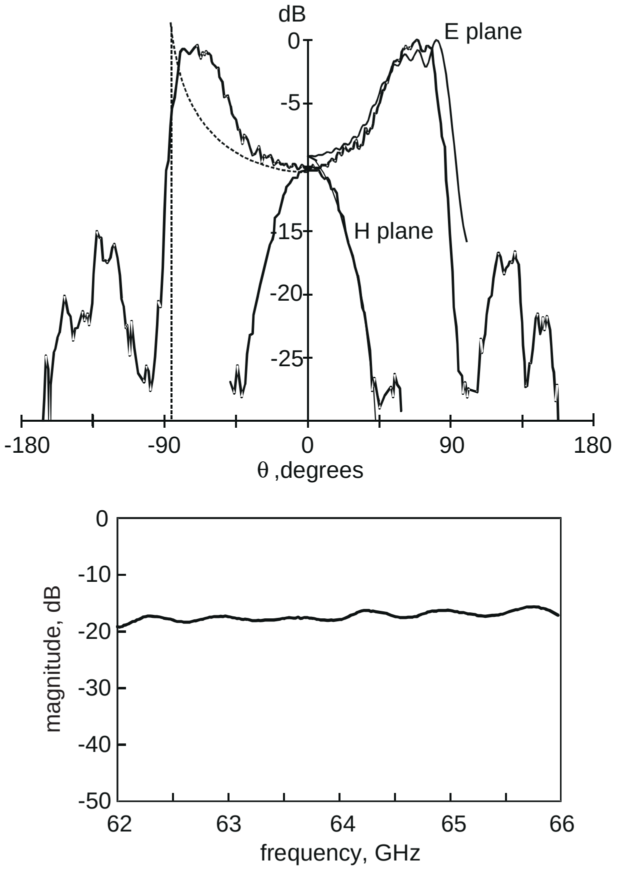


Fig. 7 - Radiation pattern of lens antenna at 62.5 GHz.

Fig. 8 is a block diagram of the transmitter-receiver (transceiver). The transmitter part consists of a transmission coding, modulation and an intermediate frequency (IF) chain. The receiver part has a pair of receiving IF chains, with a diversity switch, demodulator and decoder. The head-end, which contains about ten MMICs, is mounted next to the antennas (see Fig. 6). It is connected to the main processing unit via three IF stages: a tuneable IF at around 7 GHz and fixed IFs at about 1.5 GHz and at 160 MHz.

One of the project's activities was to reduce the number of MMICs by increasing their complexity. Fig. 9 shows the layout of the most complex MMIC produced by the project which contains four functions required for a 56.8 GHz local oscillator. These functions are a frequency doubler, bandpass filter, power divider and output buffer. Reducing the number of MMICs will also reduce transceiver size and power consumption, which is important for the development of hand-portable mobile terminals.

The RACE project has concentrated on the radio aspects of the system, so the ATM adaptation and base station infrastructure development will be carried out in a future project (see Section 5).

3. APPLICATIONS

3.1 Overview

The intention is that a wide range of applications could be offered to mobile users via MBS. These could, for example, range from providing the ambulance service with a video connection to a doctor in a local hospital, to giving access to a multimedia library for an airport traveller. It is of great interest to the broadcast industry that the widest possible range of applications is found for MBS to increase its popularity, thereby helping to reduce hardware costs as a result of widespread use.

It is obvious that installing an MBS along city streets would be initially expensive with such a small cell size, so the project has carried out a study of potential users. It has been found that business and industry are becoming very interested in using broadband wireless LANs to reduce cabling and to enable more flexible use of buildings. MBS is well suited to indoor use where the building structure provides RF isolation at 60 GHz. It is suggested that MBS might evolve from an initial use in CPNs, which are then interconnected in business areas and industrial estates to form the first public systems.

The broadcast industry is potentially a significant first-user of MBS[14]. It is therefore important to examine possible ways of using the system in order to provide feedback for its further development. A number of ways are outlined.

3.2 Television Outside Broadcasts

Wireless operation of cameras at an Outside Broadcast (OB) is attractive, as it would reduce the amount of cabling that would have to be installed at a site, so speeding the set-up time. Radio-cameras are already in use, but the problems due to multipath in analogue FM systems are very familiar to users. Even though some novel solutions have been developed which can work well in many situations[15], they are still limited by the basic modulation method.

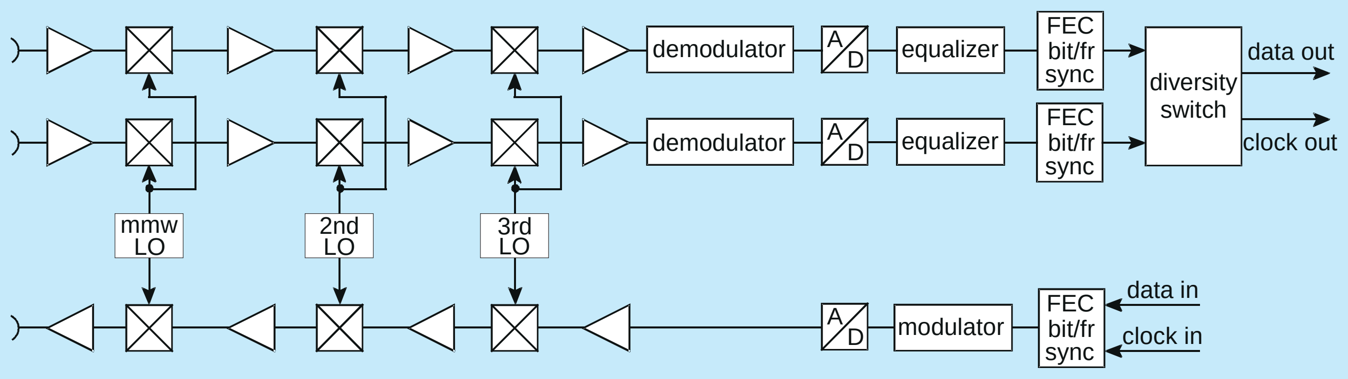


Fig. 8 - Block diagram of the MBS transceiver.

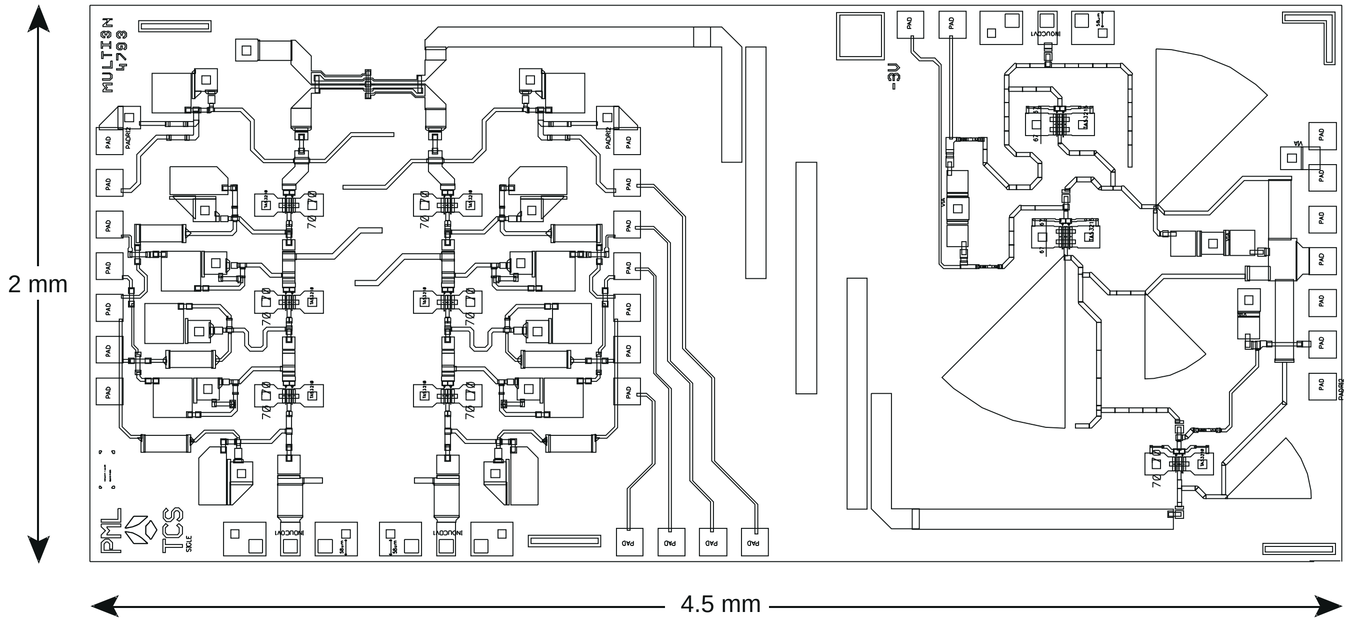


Fig. 9 - An example MMIC layout.

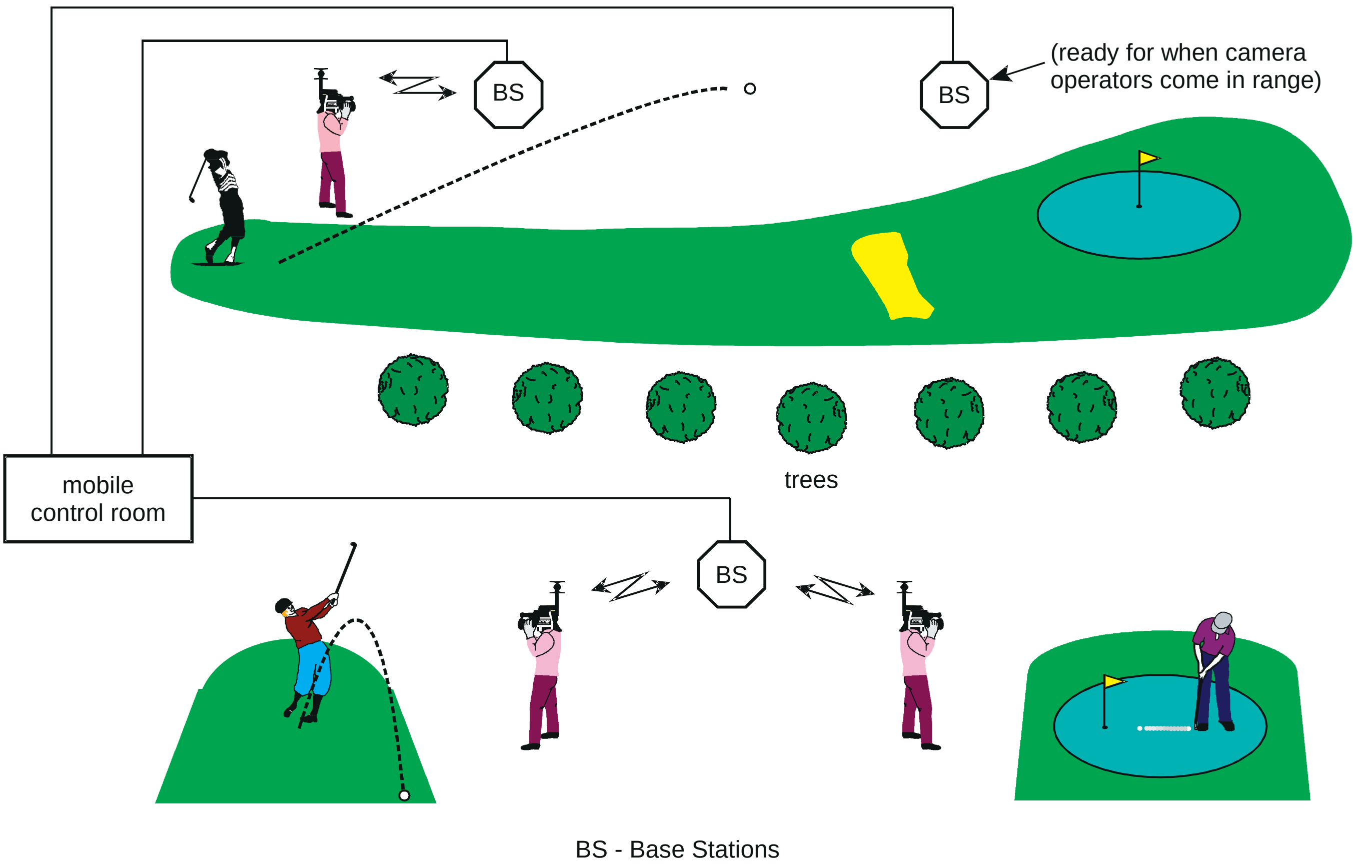


Fig. 10 - MBS being used for a golf outside broadcast.

Digital radio-cameras offer the promise of greater reliability through being able to add error protection to the digital code. Combining this with MBS's diversity reception and cellular coverage techniques, gives MBS the potential to provide a network that is simple to set up and use. Fig. 10. shows how MBS might be used to cover a golf match. The set-up procedure simply consists of deploying a number of base stations at strategic positions around the golf course. The number and position of the base stations will depend on their coverage and the geography of the site. Base stations can either be connected back to the mobile control room using light-weight optical cables, or point-to-point microwave links. These links could even be based on MBS hardware, perhaps using 40 GHz.

Cameras within the coverage areas of the base stations can move freely about, in order to follow the sporting action. The system is simple to use in operation; for example, there is no need for receive-dish panning. The system automatically re-routes the signal via different base stations as the camera is moved or if path blocking occurs. Installation of base stations on helicopters or balloons may be a useful for some applications; for example, with cameras on racing cars.

MBS is designed to work with a broad range of signal bit-rates. This means the system can handle the other communications needs at an OB, such as the programme audio, talkback, reverse video and remote control. The MBS project was provided with much detailed information on these communication requirements, including the quality criteria. This information was used, along with the requirements of other potential users, in the design of the MBS architecture. It was seen that the communications at an OB can be broken down into a number of logical networks; for example, video, audio, and individual talkback networks, which can all coexist on the same MBS, but be managed independently. MBS could also be logically partitioned into 'closed user groups', enabling more than one broadcaster to share the same system and maintain privacy.

Signal quality from radio-cameras will depend on the error protection and on the type of video codecs used. MBS intends to offer a user capacity of 34 Mbits/s per RF carrier, to which it would add extra error protection bits. In principle, this gives sufficient for a 625-line video signal coded to ITU-R Rec 723 or an HDTV signal. The use of bit-rate-reduced signals at this point in the chain is a subject for discussion beyond the scope of this Report, but MBS can offer multichannel operation in order to increase capacity to improve the signal quality.

On an open flat site (the worst case situation regarding interference between neighbouring cells), seven RF channels are available in each of the 1 GHz up- and downlink bands in a network of MBS cells. This assumes that each cell is divided into three sectors and that there are 21 channels per 1 GHz band. Five channels might be used for five radio-cameras, leaving two channels to be used for TDMA multiplexes of other signals. Capacity could be increased by using some of the available downlink band because of the asymmetric signal flow at an OB.

If 140 Mbits/s was deemed necessary to maintain the quality of HDTV cameras, then it could be arranged to operate only the ‘on-air’ cameras in multicarrier mode, with the other cameras providing a lower definition picture using one RF carrier for preview monitoring. The MBS could be linked to the vision mixer so that as cameras are put ‘on-air’ they are given a full bit-rate channel automatically.

Note, that if the OB is sufficiently close to a road that has a public MBS, then it could be used to send the signals back to the studio. The short range at 60 GHz is helpful for frequency planning with respect to such a public MBS.

OBs held at indoor locations such as concert halls and theatres, can be considered to be similar in operation to studio radio cameras (as discussed in Section 3.4).

3.3 Electronic News Gathering

Electronic News Gathering (ENG) can be thought of as a small OB; therefore, much of what was said above is relevant. An ENG vehicle could be equipped with one or two MBS base stations which could either stay in the vehicle or be removed to suitable locations; for example, round Parliament Square, for interviewing Members of Parliament. A radio-camera would then simply be used to cover the event as necessary, without having large numbers of cables causing a trip hazard in a public place, Fig. 11. The signal can be sent back to the studio over the public MBS if available, or a 40 GHz point-to-point link, based on some of the MBS hardware, could be used. It would also be possible for the radio-camera to communicate directly with any installed public MBS, avoiding the need to provide a specially equipped vehicle.

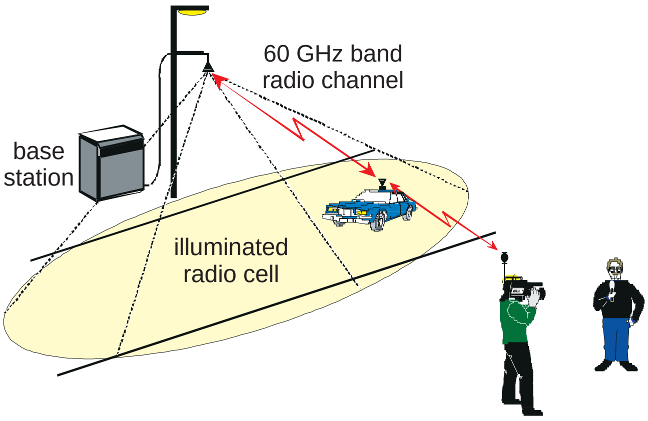


Fig. 11 - MBS being used for ENG.

3.4 Studio radio-camera

Increasing the freedom of movement of cameras in studios and at indoor locations can allow more creativity in programme production, Fig. 12. Although this has been tried with analogue FM radio cameras, programme makers have to tolerate the significant probability of picture break-up, which limits their use for live programmes.

MBS has some inbuilt features which make it attractive for studio use. There is significant attenuation by most building materials at 60 GHz which effectively isolates each studio or room. Though the basic range of MBS is sufficient to have just one base station in each studio, RF shadowing and multipath suggest that two or more base stations be used to provide diversity. MBS incorporates the necessary automatic base station switching for diversity operation.

The RF isolation will allow more radio-cameras to be used in each studio than around one base station at an OB. The exact number will depend on the capacity required for each video signal; it could be as many as 21 radio-cameras at 34 Mbits/s, or four HDTV cameras at 140 Mbits/s. If more HDTV cameras are required, then the data-rate switching technique described for OB use could be employed.

3.5 Programme planning or editing

In broadcasting, there is already a trend towards computer-based programme editing and to the consultation of video file servers for programme planning. However, the user either needs to be close to the video storage location, or be connected to a high-speed local area network (LAN), to view video pictures with accompanying sound. Cabled LANs restrict the user to suitably equipped rooms, but a wireless LAN would enable almost any room to be used, even without preparation, together with portable computers, Fig. 13 *(overleaf)*.

Several types of wireless LAN are under development; for example, Hiperlan[16], but they tend to be based on

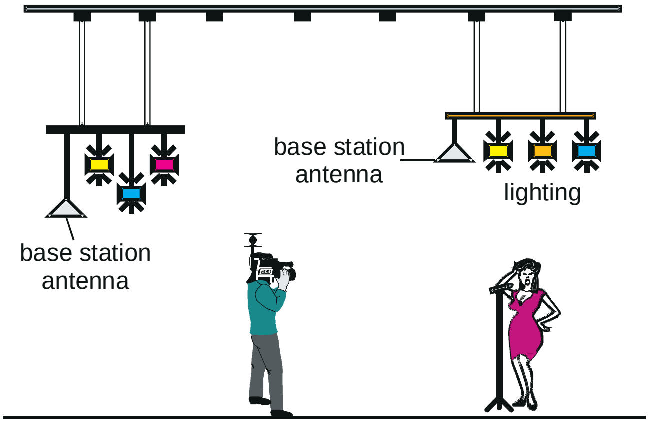


Fig. 12 - MBS being used for a studio radio-camera.

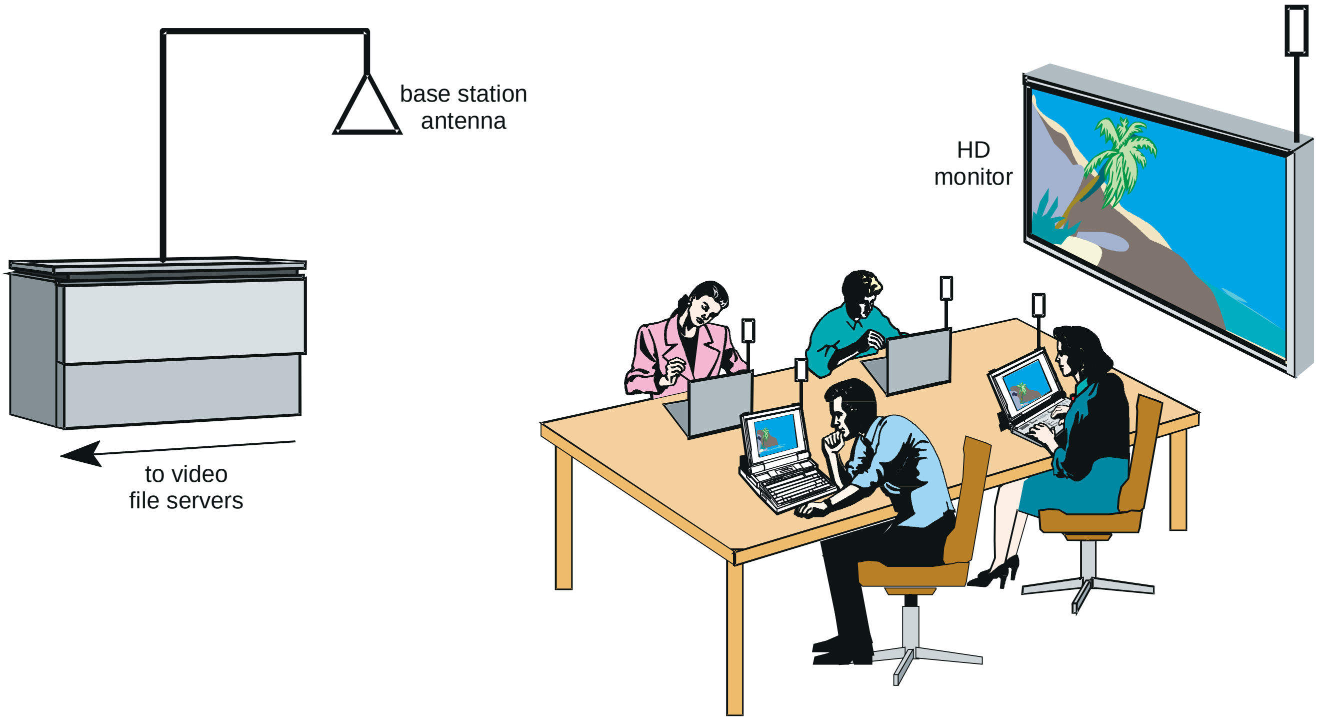


Fig. 13 - MBS being used for programme planning.

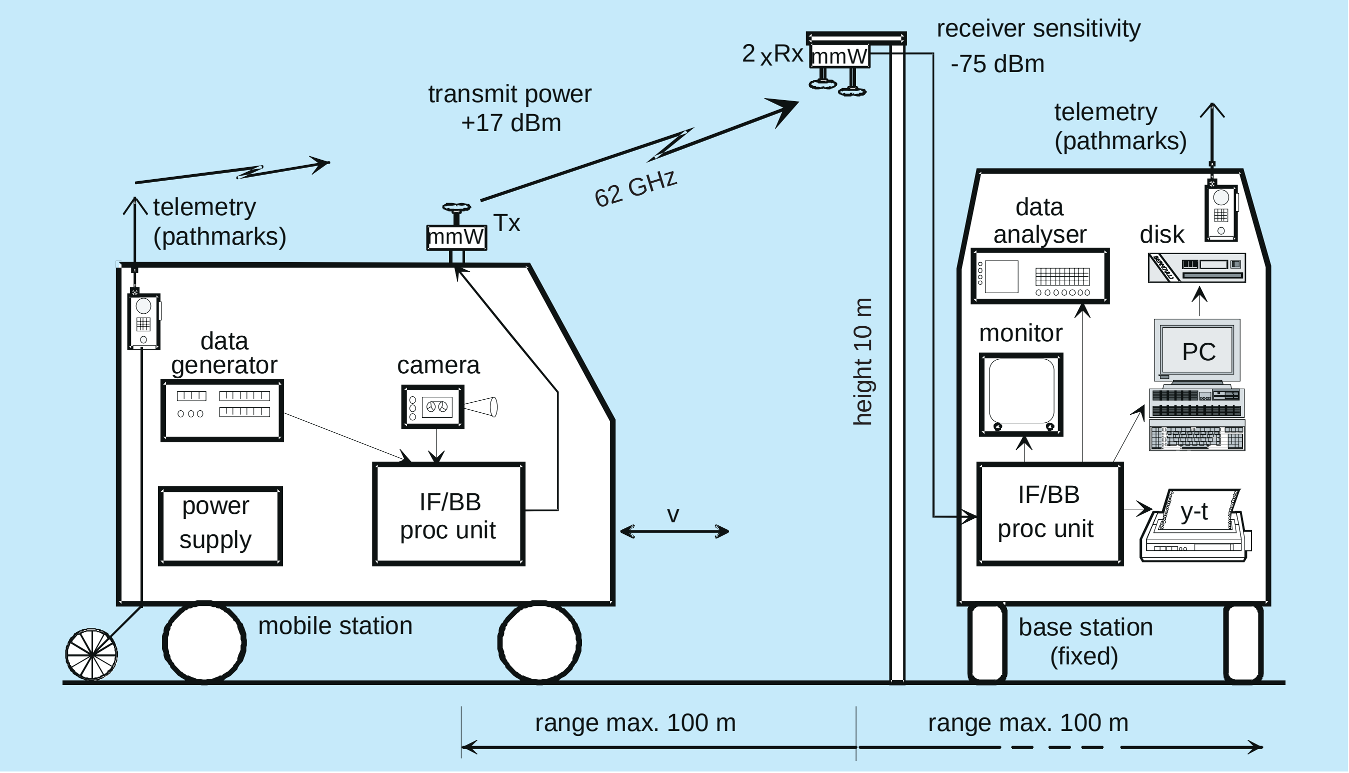


Fig. 14 - MBS demonstrator.

peer-to-peer asynchronous communications. The high capacity of MBS will allow high quality images to be viewed. Also, its ATM and B-ISDN compatibility would simplify the retrieval of images from remote multimedia libraries.

4. DEMONSTRATOR

4.1 Description

The MBS project constructed a technology demonstrator to test the feasibility of the MBS concept, particularly transmission in the 60 GHz band and the MMICs. This demonstrator consisted of a mobile and a base station creating a single cell of an MBS network. The mobile was installed in a van, as was the base station, for easy transportation to different test sites; see Fig. 14, and Figs. 16 & 20 *(both overleaf)*. A transportable hoist was used for mounting the base station's antennas and the millimetre-wave headend. The transmission of digital video and audio signals from the mobile was demonstrated in a number of different environments. Video recordings were made of these transmissions. In addition, a computer-controlled data logging system made detailed measurements of various parameters for later processing.

Trials were carried out in Ulm, Germany, at three locations; a driveway within Daimler-Benz Research on a hill outside Ulm (an open location), a driveway at Daimler Benz Aerospace premises within the town (just like an urban street with buildings and street furniture), and inside an empty disused factory (representing an indoor location). In addition to making video recordings of the actual signal received over the link, the trials themselves were video-recorded for future reference.

The procedure for the trials was to set out a straight line course of approximately 200 metres for the mobile to drive along, usually with the base station located at the centre, thus making up an elongated radio cell typical of the type needed for use along public roads, Fig. 15. In all cases, the mobile had unobscured light-of-sight transmission to the basestation when within the cell. Measurements were made with a range of mobile speeds up to about 50 km/h (limited by safety considerations).

4.2 Mobile terminal

The van, Fig. 16 *(overleaf)*, used for the mobile terminal contained a broadcast-quality video camera as the video source and a Compact Disc (CD) player as the audio source. The video signal was digitised and coded at a bit-rate of about 11 Mbits/s using a coding system based on the Discrete Cosine Transform (DCT). The video was packaged into ATM cells and ATM-multiplexed with the audio (at full bit-rate) to produce a final bit-rate of 18 Mbits/s. (The coder and multiplexer are commercially available for use in multimedia applications.)

The signal multiplex was error-protection coded and a training sequence added (for use by the equaliser in the receiver), producing a line rate of about 32 Mbits/s. This was a constant bit-rate signal; that is, there were no gaps in the data as is envisaged for the TDMA structure of an operational system. This made the system easier to devise, but it did have some disadvantages as will be seen later. The signal was then

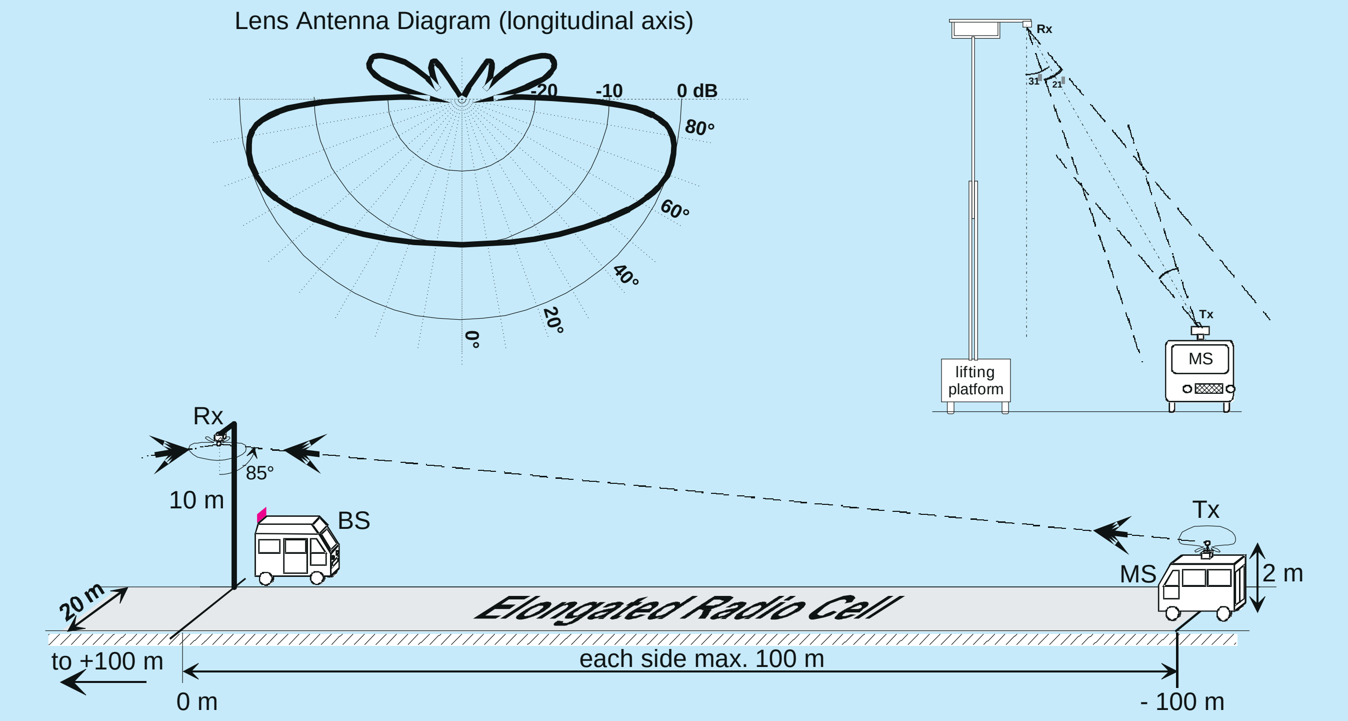


Fig. 15 - Demonstrator cell layout and lens antenna radiation pattern.

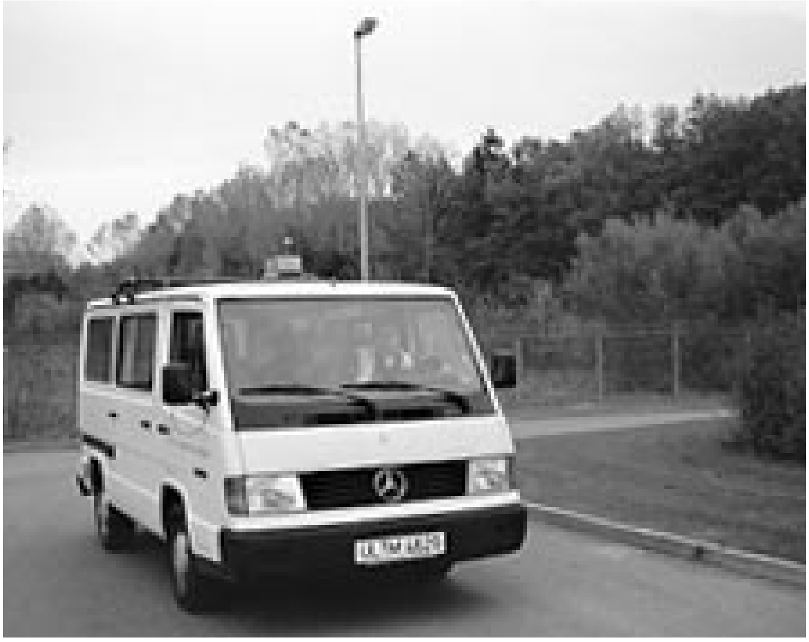


Fig. 16 - Mobile station.

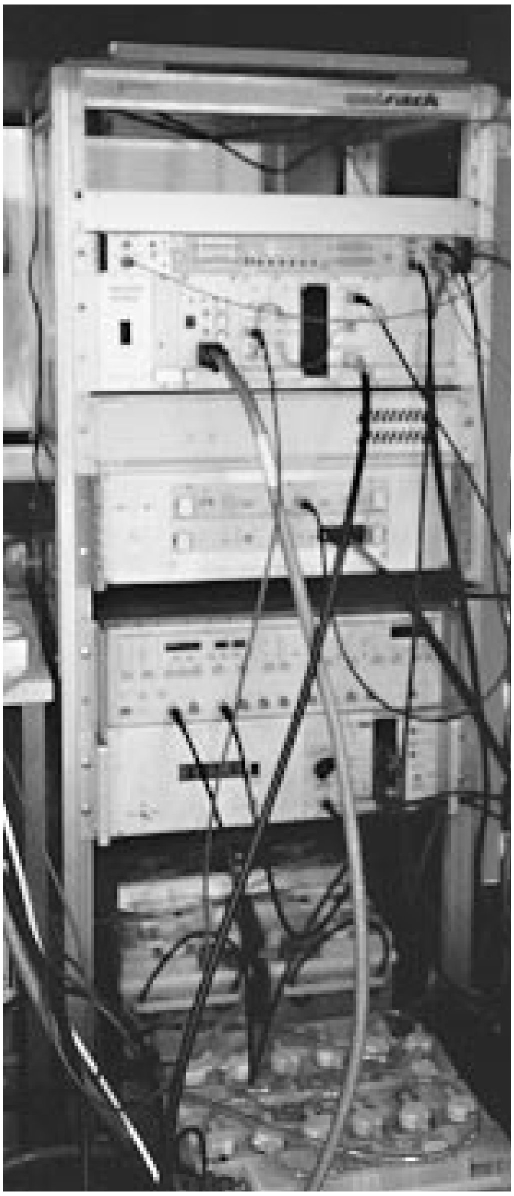


Fig. 17 - Transmitter equipment rack in

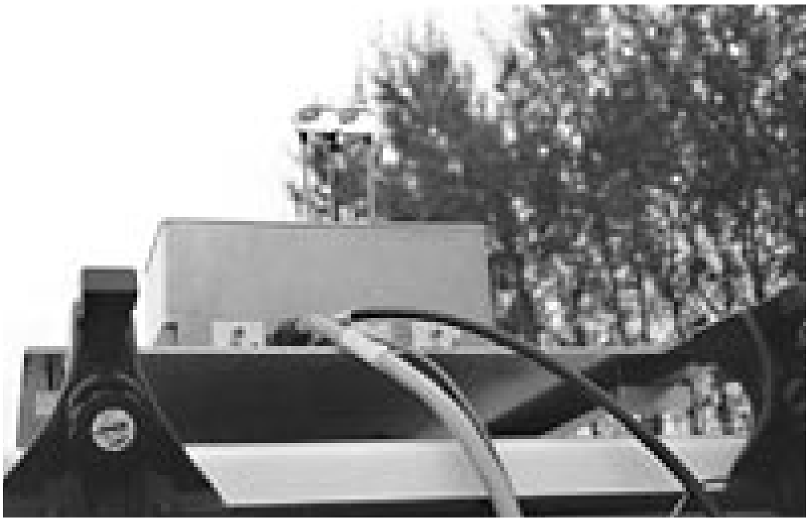


Fig. 18 - Mobile headend fitted with dielectric lens antenna.

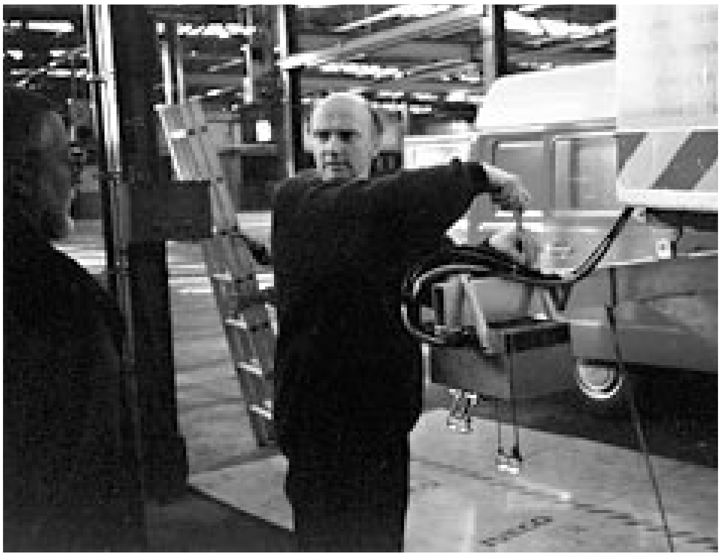


Fig. 19 - Receiver headend unit being attached to the hoist showing the two dielectric lens antennas for diversity reception.

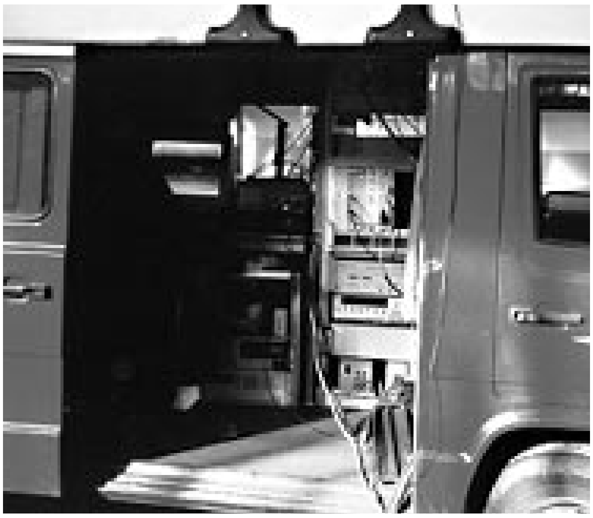


Fig. 20 - Base station.

modulated, using 4-OQAM (Offset Quadrature Amplitude Modulation) at an IF of about 160 MHz. Alternatively, a 32 Mbit/s pseudo-random bit-sequence generator could be used for bit-error-rate analysis. All the circuitry to do this was contained in a standard equipment bay mounted inside the van, Fig. 17.

The signal at IF was fed to the millimetre-wave headend in a small metal box mounted on the roof of the van, where it was upconverted to 62 GHz for emission by an antenna mounted on a short piece of waveguide protruding from the headend, Fig. 18. Most of the experiments were carried out using Plexiglas lens-shaped beam antennas on both the mobile and the base station; but some tests were done, for comparison, using horn antennas on the base station, with an omnidirectional antenna on the mobile.

4.3 Base station

The base station antenna and headend unit were positioned at a height of 10 m, using a hoist, Fig. 19. The range of the radio link was about 100 m each side of the base station. The headend had two receive antennas separated both vertically and horizontally by about 20 cm (about 40 wavelengths at 60 GHz), and two downconversion chains to bring each received signal to an IF within Band III. These signals were carried by two coaxial cables down to an equipment bay inside the base station van, Figs. 20 and 21. Each signal was then separately demodulated, adaptively equalised, and error corrected. Both signals were then fed to a diversity switch which selected the signal with

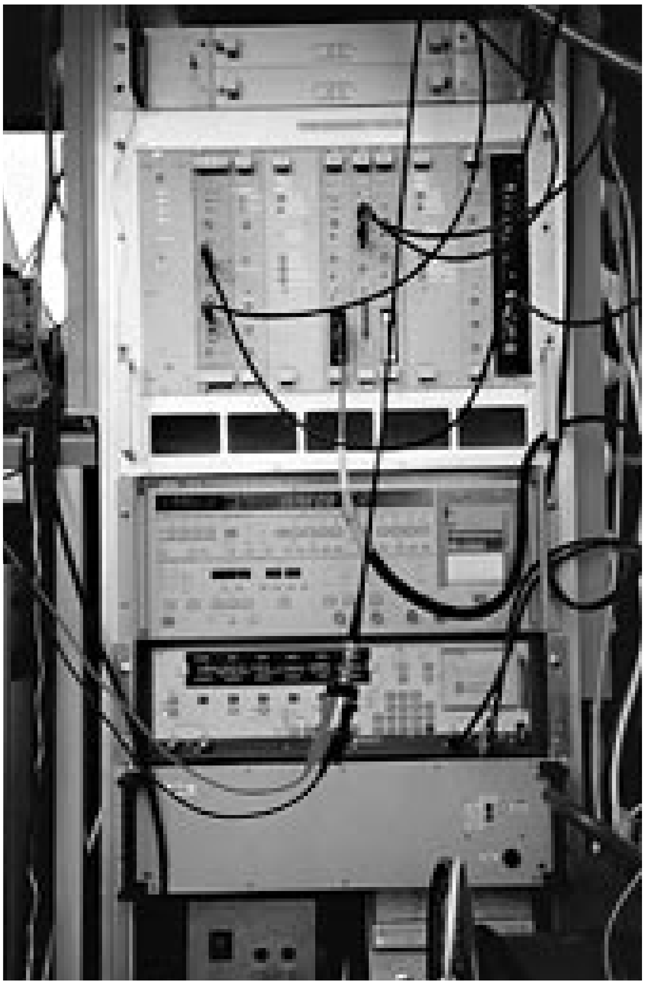


Fig. 21 - Receiver rack in base station.

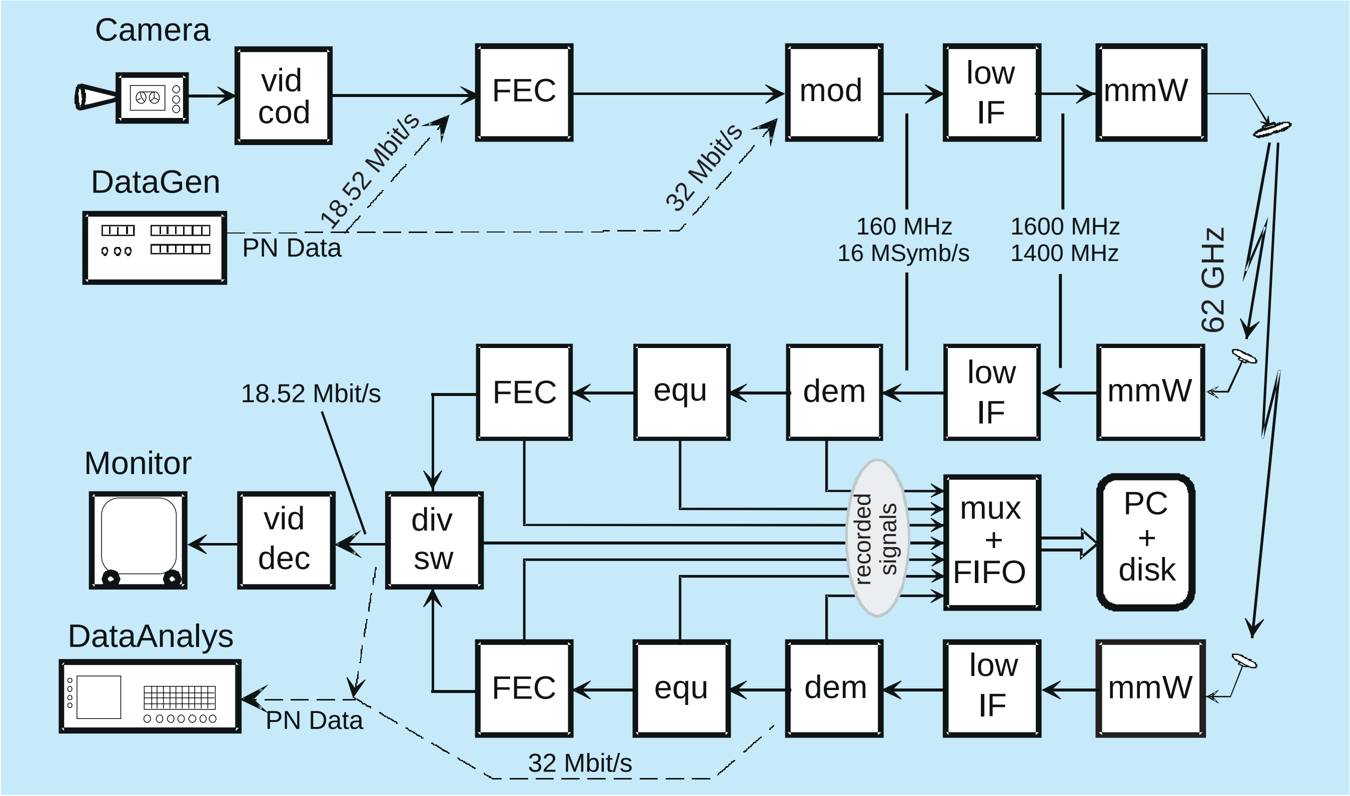


Fig. 22 - Signal paths in demonstrator.

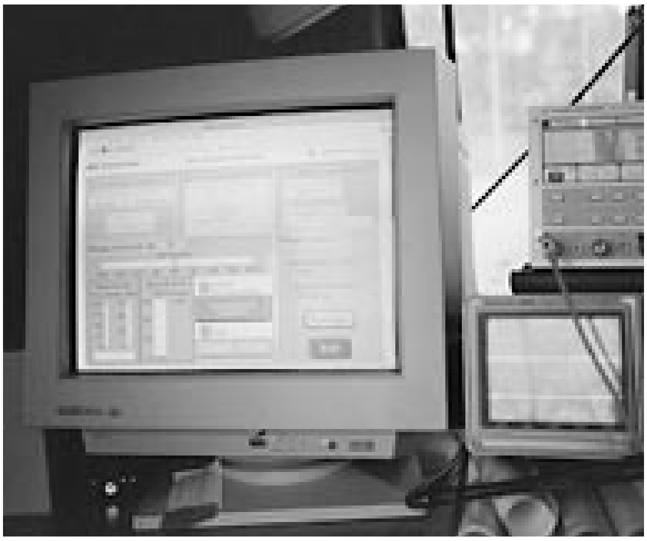


Fig. 23 - Base station data logging system.

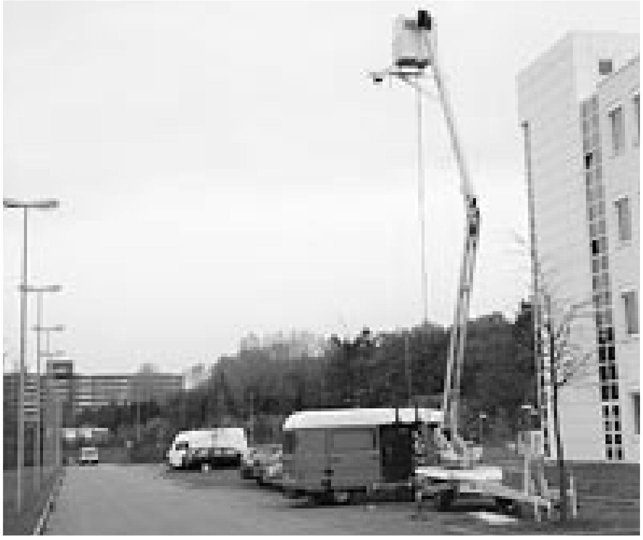


Fig. 24 - Daimler-Benz Research – open location.

the lowest error rate (not just the highest received signal level) on a block-by-block basis (Reed-Solomon error protection blocks). The signal could then either be routed to a bit-error-rate (BER) analyser or to a video-audio decoder for viewing and recording, Fig. 22 *(previous page).*

A comprehensive information monitoring system was used to log various parameters, such as the received signal strength indication (RSSI) at each antenna, Viterbi errors, Reed-Solomon errors, diversity switch activity and mobile position. The data logging system was based round LabView software running on a PC (which oversees the direct recording of the sensor information over a 96-way bus onto a Bernoulli disc drive), Fig. 23. The recorded information was then available for detailed processing.

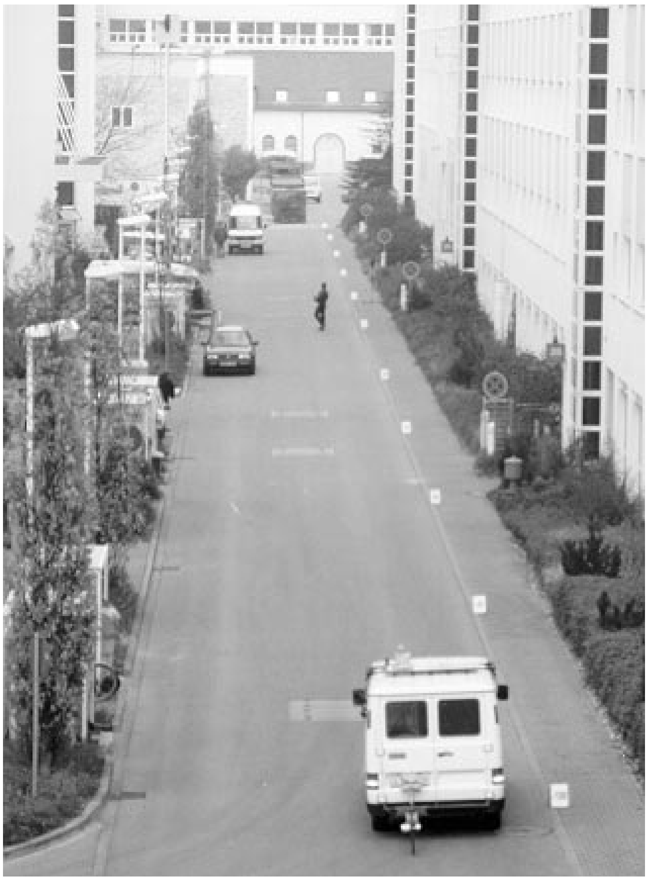


Fig. 25 - Daimler-Benz Aerospace – urban street.

4.4 Trials

4.4.1 Single channel reception

The trials in Ulm were carried out towards the latter half of 1995. The first trials using video transmission started on 24th October, but it was found that the receiver diversity switch was not functioning and so these trials were based on the use of one receiver only**.**

Outdoor locations

The demonstrator performed very well at the two outdoor locations, Figs. 24 and 25, with reliable transmission usually being obtained over most of the cell when the lens antennas were being used. Fig. 26 shows a typical result from the open location and Fig. 27 from the urban street. These figures consist of a series of graphs of recorded data against mobile position. The top two graphs show the Received Signal Strength (RSSI) from the two receivers at the base station, from which the symmetry of the radio cell is apparent. There are few deep fades within the main cell, even directly below the base station. In Fig. 26 there is a sharp fall at the right-hand end of the graph as the mobile has to turn at the end of the cell. The next graph in each of the figures is the SwSel graph which is the diversity switch position indicator (unused here). Then there is the BER from the first receiver, as the mobile traverses the course, showing that all transmission errors are fully corrected by the system except at the extremes of the cell. The bottom graph shows the path marks giving positional information on the mobile.

Little degradation was noticed during runs at various speeds up to the maximum allowable speed of

50 km/h. Movement of vehicles and people within the test area had little affect on the link quality. There were very occasional fading dropouts during some of the runs; at worst, occurring at roughly five minute intervals, which it was assumed could be easily dealt with by receiver diversity. Fig. 28 *(overleaf)* shows an error-free still that was taken from the video transmitted by the mobile in the urban street. The video and audio

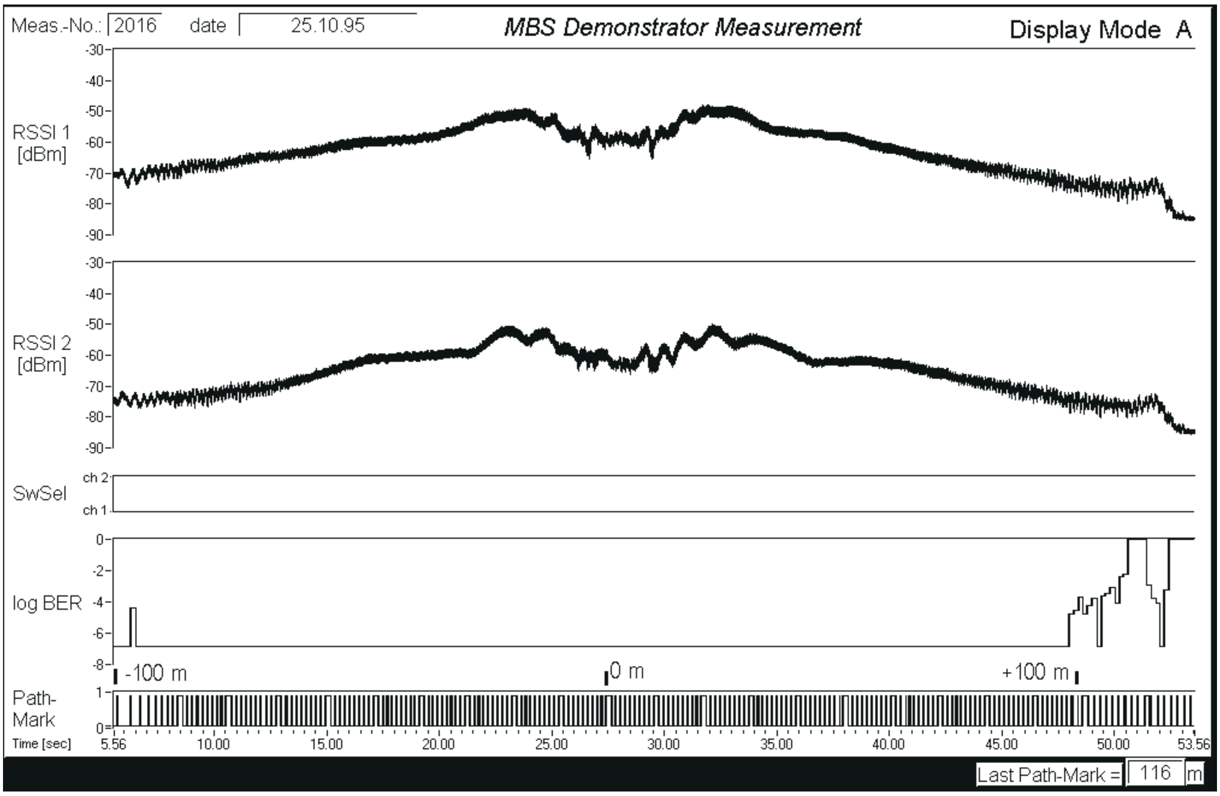


Fig. 26 - Open location at 17 km/h.

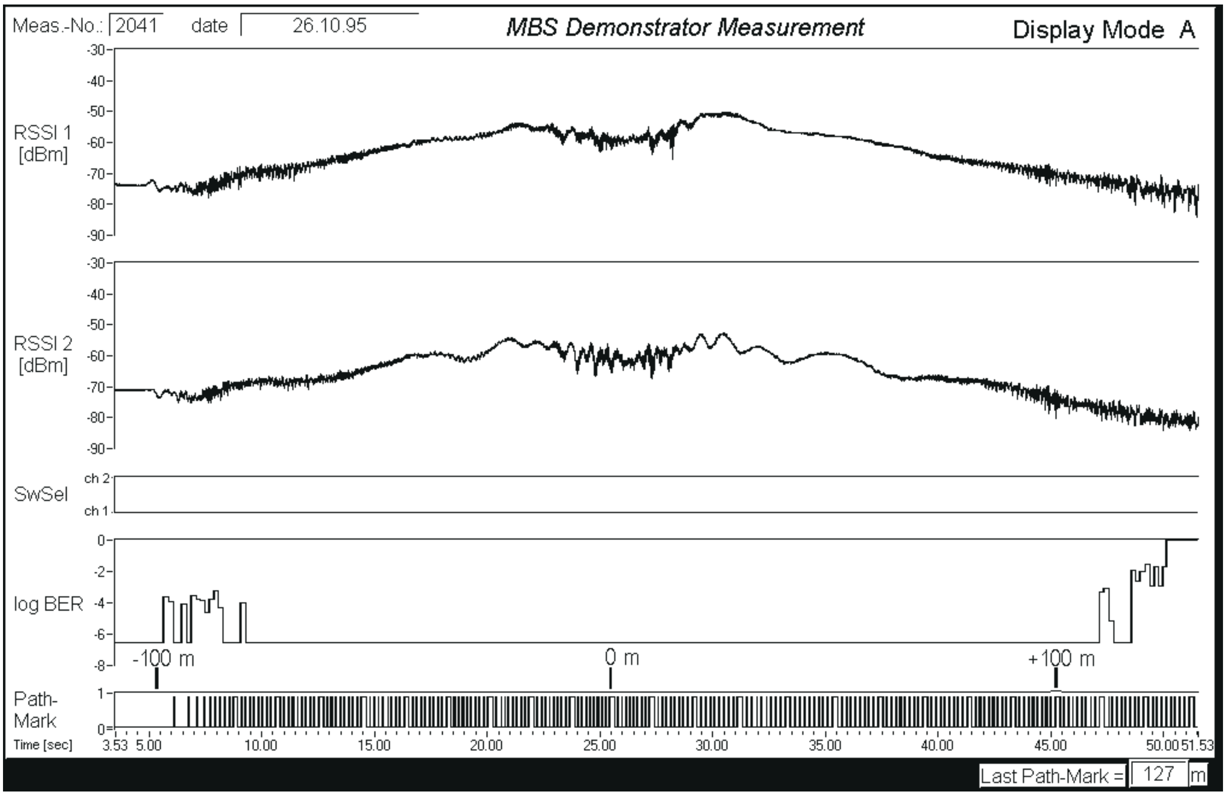


Fig. 27 - Urban street at 20 km/h.

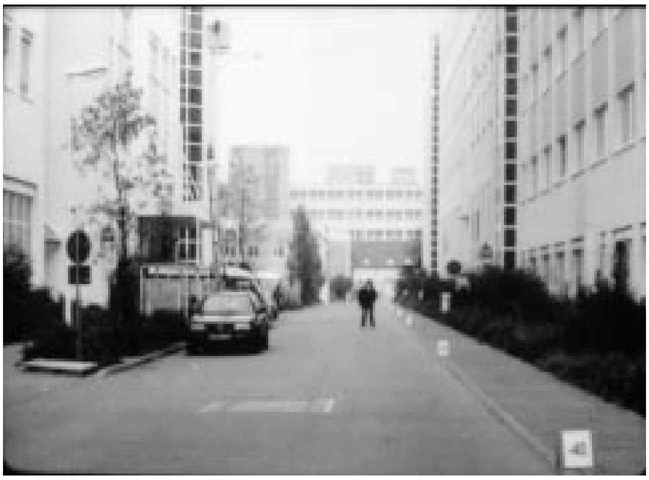


Fig. 28 - A still from the received video showing perfect picture in the urban street.

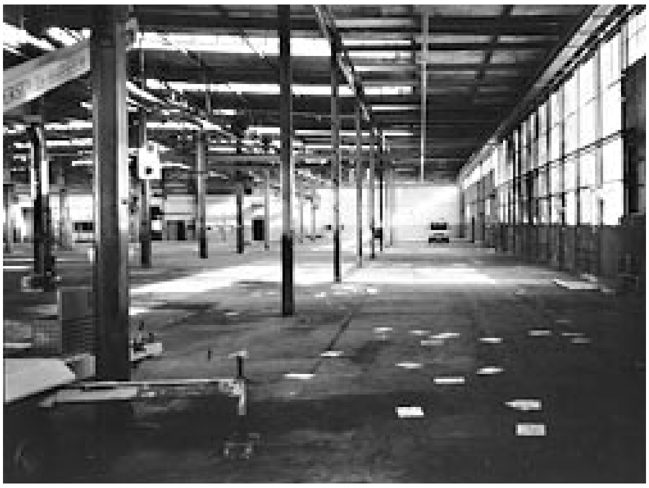


Fig. 29 - Disused factory – indoor location.

Fig. 30 - Disused factory – indoor location.

quality would broadly follow the trend of the BER graph as the mobile moved into a corrupted region, but the video signal tended to recover more quickly than the BER analyser during periods of very high error rate, because the BER analyser had to re-synchronise to a long pseudo-random sequence. There was a tendency for the transmission to be either very good or very bad, a characteristic attributed to the way FEC operates and the near optical characteristics of millimetric-wave propagation.

Indoors

The performance was less reliable in the empty factory, Figs. 29 and 30. There were many dropouts due to multipath, amounting to about 30–40% of the transmission time within the available range (about ±65 m), limited by the size of the factory. Fig. 31 shows the

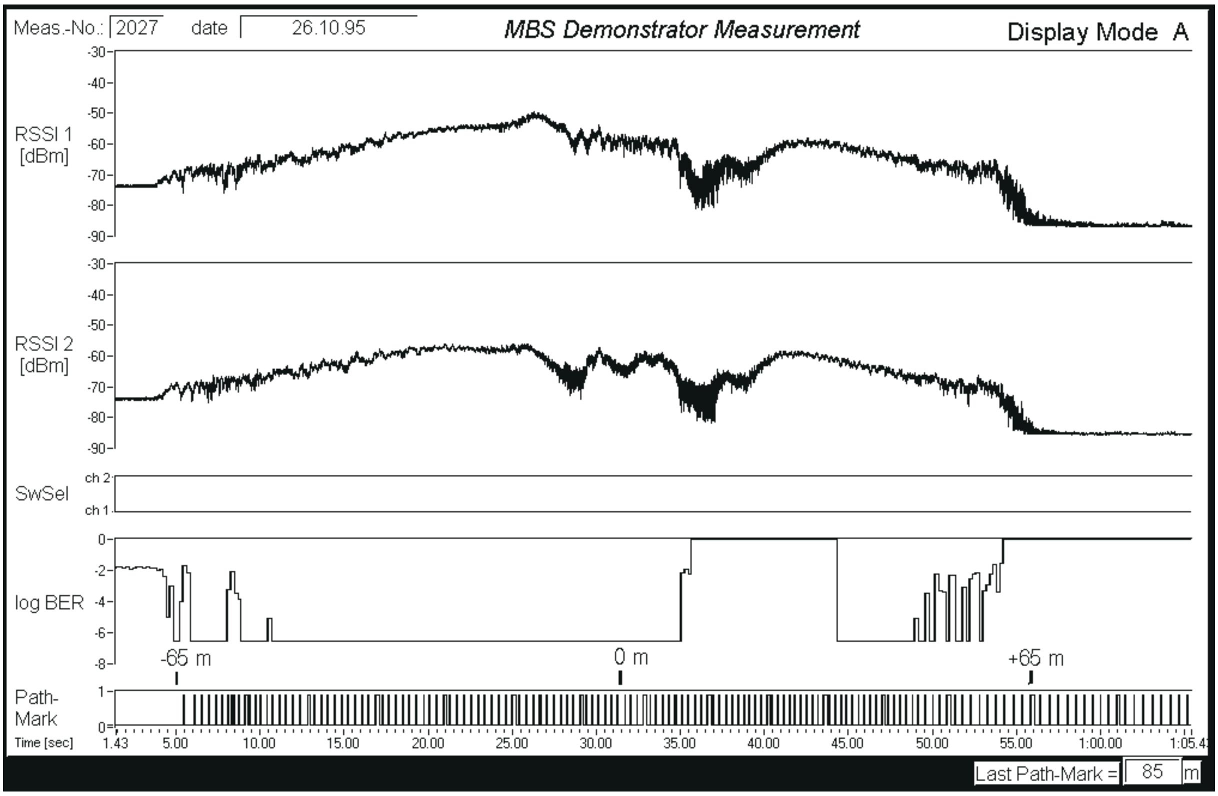


Fig. 31 - Factory at 9 km/h.

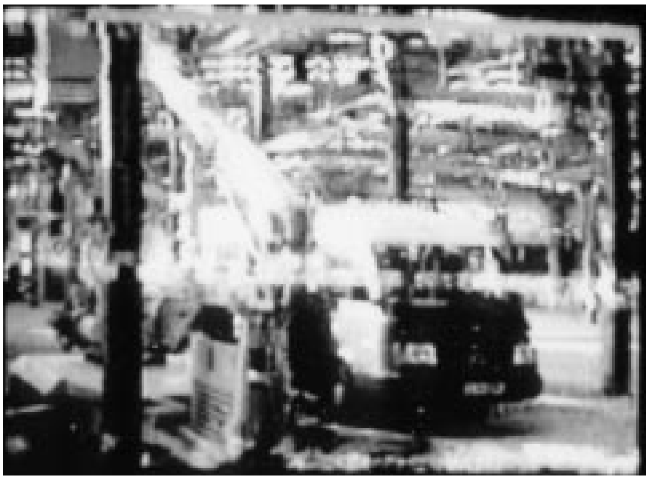


Fig. 32 - A still from the received video, showing multipath break-up.

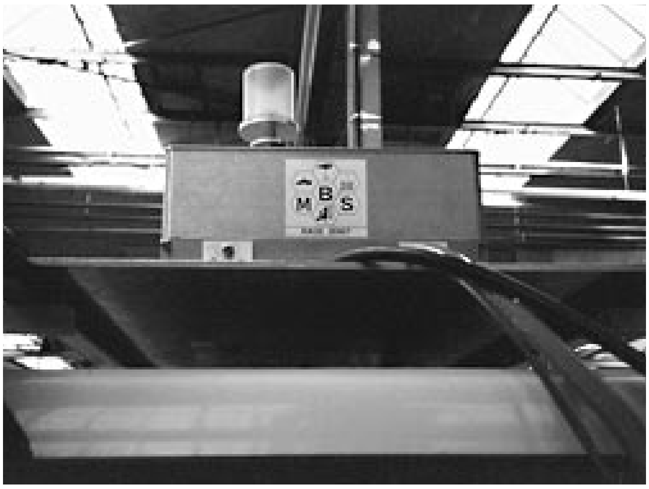


Fig. 33 - Mobile headend fitted with an omindirectional antenna.

RSSI and the BER recorded during one of the runs. There is a block of fades on both channels at the left-hand side of the graph, starting about 10 m away from the base station. There is a corresponding period of poor BER, which does not recover until well after the signal recovers, due to the time required to re-synchronise the BER analyser. Fig. 32 shows an example of a corrupted video frame displaying the characteristic blocking pattern of DCT coding.

It was suspected that a major factor contributing to this poor performance was that due to the path of the mobile being very close to one of the factory walls, giving the possibility of a strong reflection from it, which may have been the cause of the large block of fades observed in Fig. 31. It was also evident that both

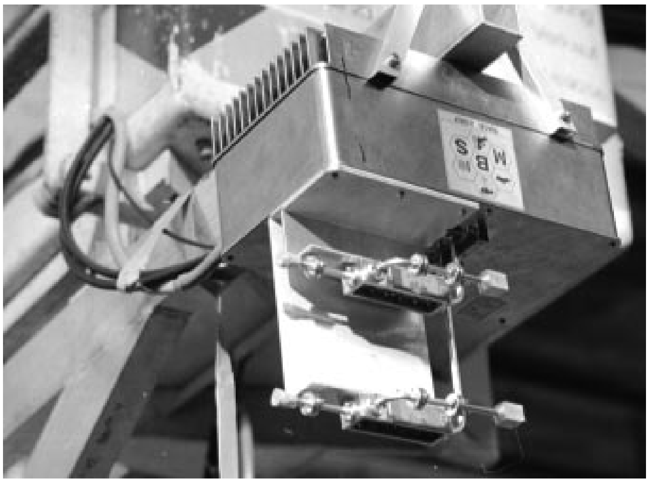


Fig. 34 - Horn antennas fitted to the receiver end.

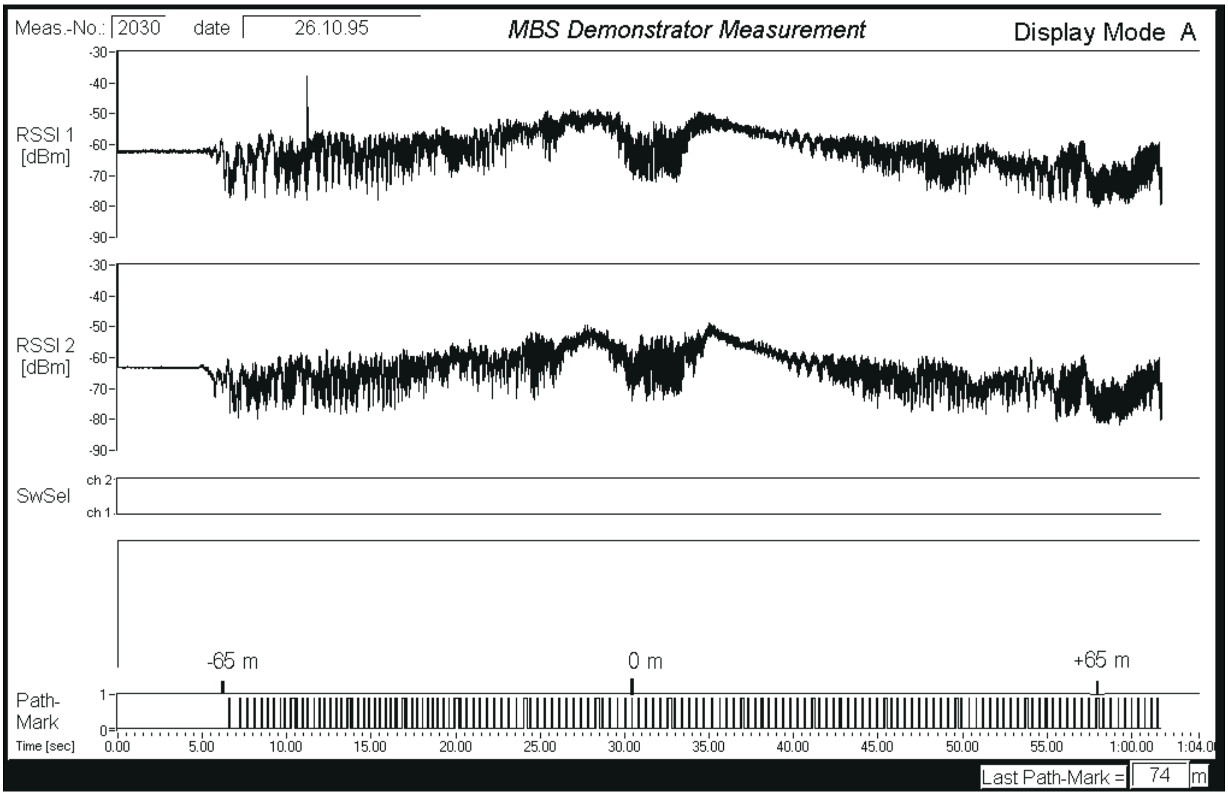


Fig. 35 - Results using the omnidirectional/horn antenna combination in the factory at 9 km/h.

receivers could be affected by a large reflection arriving at each receiver antenna at the same time, due to the width of the reflection. This situation is traditionally thought to be unimportant, because the individual fading notches on each receiver channel caused by the reflection should be uncorrelated, provided the antennas are separated by a distance that is large compared to the RF wavelength. This ignores the finite receiver lock-up time in comparison with the fade rate. It would seem that it would be better to separate the receive antennas sufficiently to reduce the probability of them ‘seeing’ the same reflection.

Antenna experiments

In all locations, the best results were always achieved using the lens antennas. Replacing them with an omnidirectional slot antenna on the mobile and a waveguide horn antenna on the base station, produced a much degraded performance, Figs. 33 and 34 *(previous page)*. Transmission also became more dependent on the movement of people and vehicles within the test area, showing that multipath is the major factor in causing degradation of the link. Fig. 35 *(previous page)* shows that the RSSI in the factory has deep fades over most of the path, which prevented the BER measuring equipment from locking up, hence no BER graph is shown. It was observed that the video coder would lock up occasionally, giving brief periods of video transmission with the mobile within 15 m of the base station.

4.4.2 Diversity reception

Another set of trials, using receiver diversity, commenced on the 8th November. Due to the tight time schedule, all the trials were carried out in the urban street location. Again, video recordings were made of these trials. A final set of trials was carried out from 4th December to obtain further measurement data, particularly at a very slow speed.

It was found that when using the lens antennas, the diversity reception did seem to eliminate the effects of the occasional random dropout occurring when the mobile was well within range of the base station; but there was no significant increase in range at the extremes of coverage, due to the rapid transition from no errors to very high error rates at the extremes of the cell.

Fig. 36 shows results obtained without the equaliser in each receiver. Note that, in addition to the graphs seen in previous figures, there are four additional graphs giving details of the errors detected in each of the two receivers; VITERR is the number of errors from the Viterbi decoders, and RSUB shows Reed-Solomon block errors. Fig. 36 shows that the major part of the cell has only a low level of fully-correctable errors over most of the mobile’s path. Note that, to the left of the centre, a pair of uncorrectable Reed-Solomon blocks in the second channel do not corrupt the overall BER, because the diversity switch (SwSel) detects this and selects the other channel, as expected. Fig. 32 confirms that the onset of errors at the ends of the cell is too rapid for diversity reception to give much benefit.

Fig. 37 shows the effect of including the equaliser in each receiver. It appears that the equaliser has improved the first channel but not the second channel, in that the

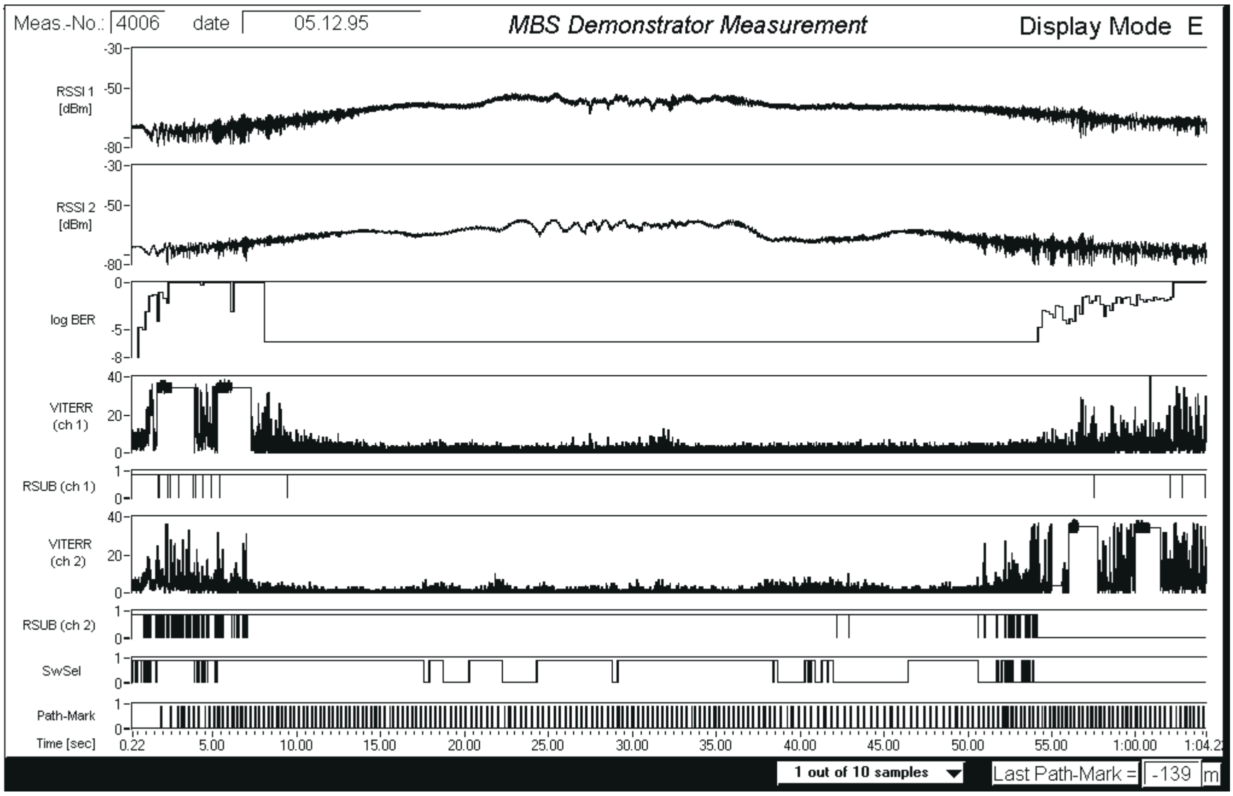


Fig. 36 - Urban street without equaliser.

diversity switch almost continuously chooses the first channel. This may have been due to a problem with the equaliser on the second channel. However, the effectiveness of the equaliser on the first channel is clear, allowing error-free transmission over most of the cell.

Fig. 38 shows a run carried out at 0.2 km/h (~5 cm/s) to see in detail what happens as the mobile moves through a fading region, about 70 m away from the base station. It can be seen from the RSSI graphs that the fades are more highly correlated than is usually

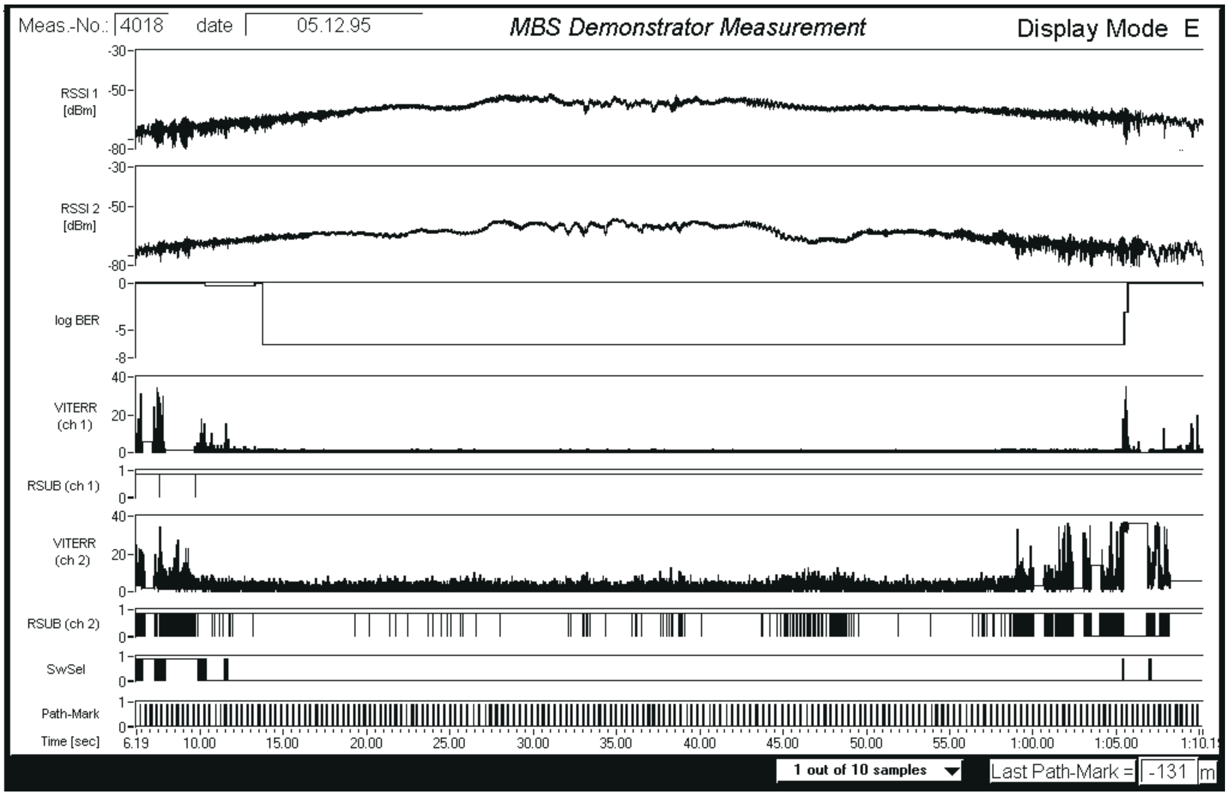


Fig. 37 - Urban street with equaliser.

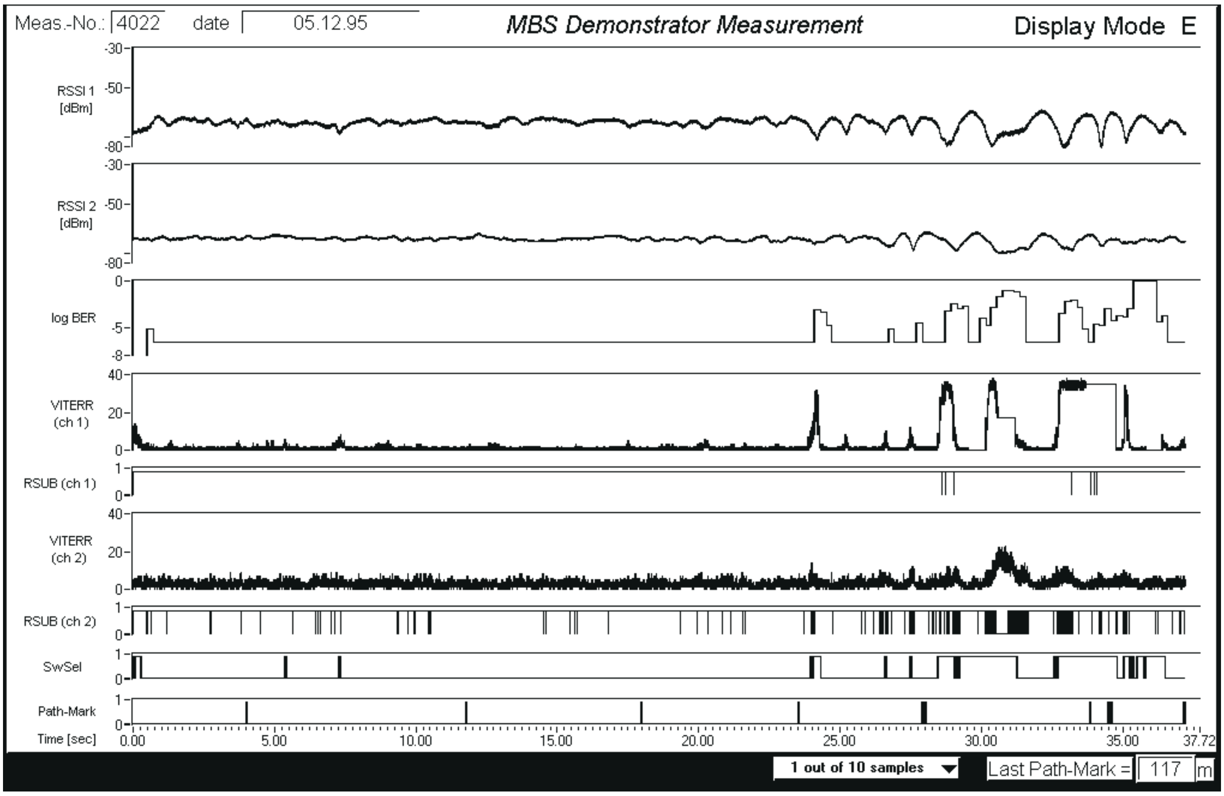


Fig. 38 - Urban street with mobile moving slowly 70 m from base station.

expected, so both channels have errors at the same time and supporting the suggestion that the two receive antennas are too closely spaced.

Antenna experiments

Fig. 39 shows results obtained with the slot omnidirectional antenna on the mobile and the horn antennas on the base station again; this time in the urban street and with the diversity switch operating. Due to the problem of having the receiver and BER tester properly locked up at the start of the test, the mobile was started at 10 m distance from the base station and then driven away from it. (The mobile did not start directly below the base station because it would have been out of the main lobe of the horn antennas.) It can be seen that the BER only stays low for a few metres at the start of the run, with the diversity switch operating frequently in an attempt to find the better signal. At longer distances, the received signal is mostly dominated by multipath and the system is not able to regain lock, even for the few brief periods of good reception on each channel individually.

Experiments replacing the omnidirectional antenna on the mobile with a dielectric lens antenna, while keeping the horn antennas on the base station, showed that the range of error-free transmission can be increased to over 30 m, due to the increased gain and selectivity of the dielectric antenna.

Fig. 40 is a very slow run at 5 cm/s with the slot and horn antennas, showing much operation by the diversity switch. A few periods of error-free transmission are obtained this time, because the bit error-rate tester has time to lock up.

4.4.3 Comments on trials

These trials successfully showed that it is possible to get reliable transmission of broadband signals from a mobile in the 60 GHz band. However, the single-carrier 4-OQAM modulation is affected by multipath; so measures to reduce it, or negate its effects, were found to be essential. The combined convolutional and block coding FEC worked very well, as long as the received signal did not suffer severe fading. The adaptive equaliser could reduce some of the effects of fading, but these trials showed that multipath signals have a major effect, so it is worthwhile trying to reduce their pickup.

The vast difference in performance between the dielectric lens antennas and the horn/slot omnidirectional combination showed the advantage of just ‘illuminating’ the main area where the mobiles are expected to be; also, this helped to avoid the influence of nearby buildings or other structures that could reflect the millimetre-wave signal.

Diversity reception did not work as well as expected. The cross-correlation coefficient of the RSSI’s in each receiver was calculated from the RSSI measurements from some of the runs. It was found to be typically 0.29, which should have been sufficiently low for diversity reception to work. However, it was noticed during the trials that both channels would often show fading behaviour in broadly similar places. This was when the mobile entered regions where a reflection

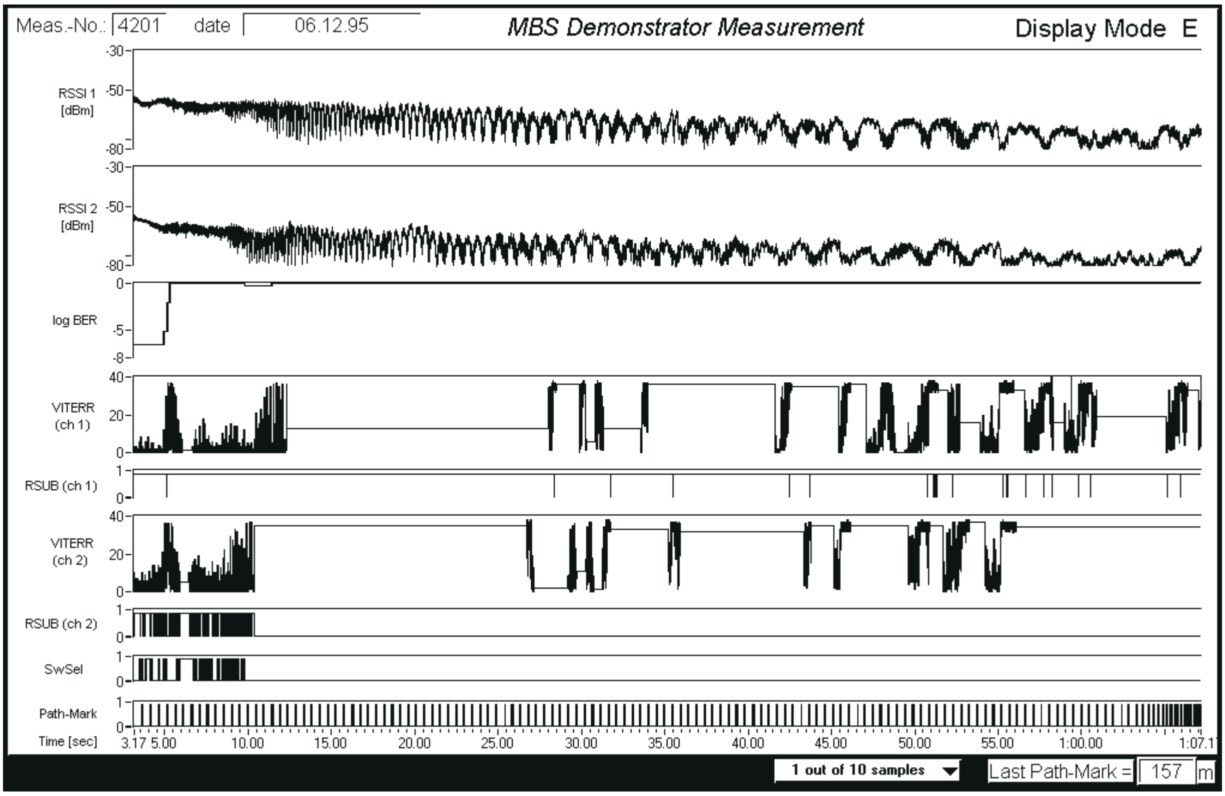


Fig. 39 - Urban street using the omidirectional/horn antenna combination with mobile starting near to base station.

from a building, say, is picked up by both of the receiver antennas. Even though the individual fading notches were not highly correlated with each region, the lock-up time of the decoding process was comparable with the transit time of the mobile between fades. This made the outages overlap significantly and so obviated most of the advantage of diversity reception. This may not be such a problem for a full MBS using TDMA packets that are short compared to the fading rate, and give the opportunity to use ARQ techniques. This is something that the trials in the follow-on project should be able to verify (see Section 5).

The experience of these trials indicates that when considering the siting of antennas for diversity reception in a millimetric-wave system, the quasi-optical nature of the propagation suggests that the antennas need to be separated sufficiently to minimise the probability that they are both within the beam of a reflection at the same time. This should reduce the probability of outage caused by the finite lock-up time of the receiver clock recovery, and the speed at which the mobile moves through the individual fades.

5. DISCUSSION

The popularity of MBS will depend on demand for broadband wireless capacity. Video is becoming important in business for video-conferencing and multimedia services, and although such services might be accommodated by wireless LANs, the quality of the low bit-rate video coding required is questionable. Once the novelty has worn off, then business users will start to demand higher quality video coding without long coding delays, which are precisely the same as the broadcast industry's requirements.

Timescales depend on a number of factors, but MMIC development is proceeding very quickly and some estimates indicate that chips suitable for hand-portable terminals could be available as soon as 1998. Complete MBS systems suitable for indoor use could appear by about 2003, and the public MBS could start by 2008 in limited geographical areas. The speed of growth of the public MBS is very difficult to judge, because it will depend on the growth of applications more than the development of the technology.

The MBS demonstrator showed that transmission of digital video from a vehicle over a 60 GHz millimetric-wave link, at a gross bit-rate of 32 Mbits/s, is possible. The demonstrator was not meant to represent the practical implementation of such a system, but it did prove the principle. These trials illustrated that excellent transmission quality can be achieved if care is taken to use the appropriate antennas so that only the target area is covered, and to minimise multipath. Diversity reception can help reduce dropouts due to fading, but the receiving antennas need to be sited so as to diminish the chance of them being within the same specular reflection.

It is important that the broadcast industry be involved in the further development of broadband cellular radio mobile networks and wireless LANs, in order to influence hardware and system development. In particular, those outside the broadcast industry are not fully

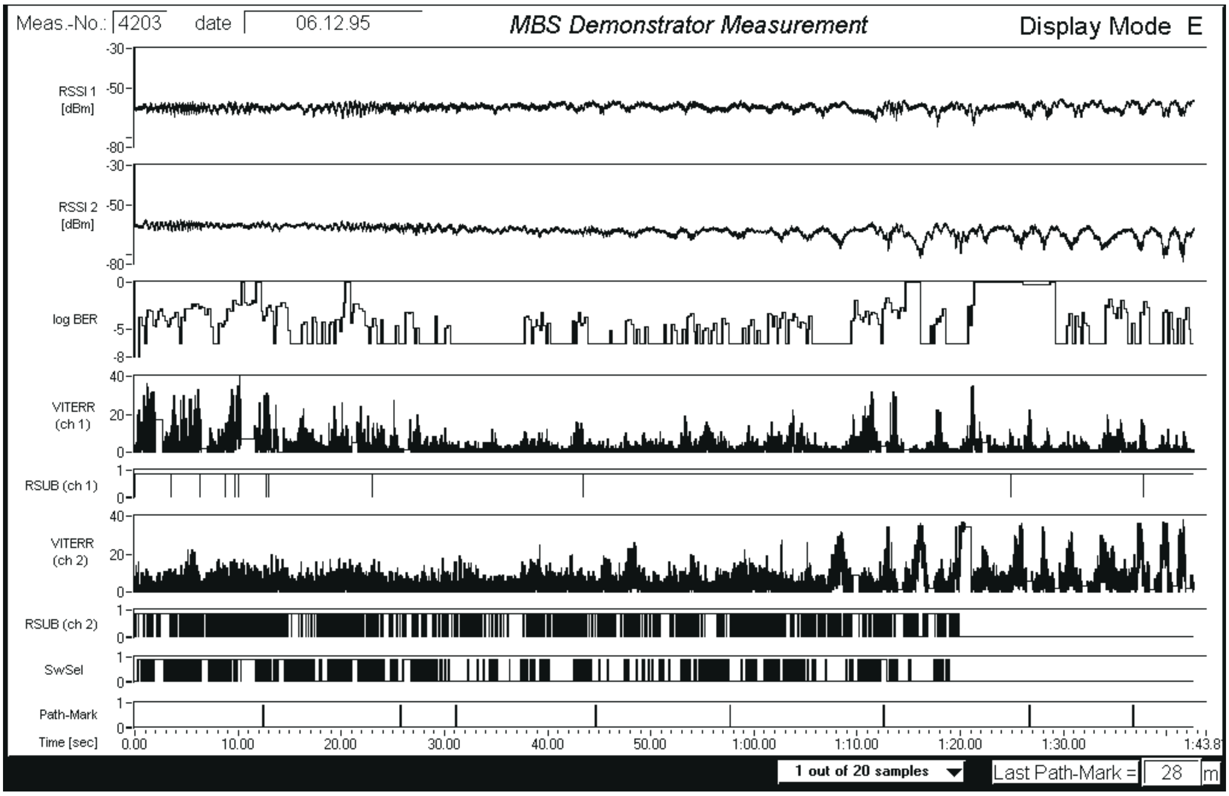


Fig. 40 - Urban street using the omidirectional/horn antenna combination with mobile moving very slowly 20 m from Base Station.

aware of the difference between contribution and distribution quality signals and the importance of low end-to-end delay in coding and transmitting video and audio signals. It is interesting to note, that there are several ACTS projects addressing the indoor wireless LAN aspects; areas identified in the RACE MBS project as having the largest initial market. However, many broadcasting applications require all the mobility aspects of an outdoor MBS.

A new ACTS project (AC 204) called SAMBA (System for Advanced Mobile Broadband Applications) will provide a trial platform of two mobiles and two radio cells to demonstrate the aspects necessary for an operational MBS, such as:

- Call handover between cells,
- ATM packet transmission,
- Multiple user access techniques,
- Interworking with the fixed network.

6. CONCLUSIONS

The work of RACE Project MBS to develop a broadband digital cellular radio system operating in the 60 GHz band has been described. The system is intended to be an ATM-compatible wireless extension to the B-ISDN, for installation either as a public network along city streets or as a customer premises network for business and industrial premises. The uses of MBS in the broadcast industry has been described. A possible private MBS could be used to quickly set up coverage at an outside broadcast for digital TV or HDTV cameras, or be used inside studios. A public MBS could provide dial-up connections for ENG use. The results of trials with the project demonstrator have been reported, and have shown that the millimetric-waveband can be used to reliably transmit high quality video and audio signals from a mobile moving at speeds of at least 50 km/h. Now that the basic technology is proven, a new ACTS project (SAMBA) is building up a trial platform of at least two radio cells and mobiles to demonstrate the aspects necessary for an operational MBS that could be used for broadcast industry applications, such as radio-cameras.

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